PRICE TEN SHILLINGS AND SIXPENCE.

THE JOURNAL OF The Institution of Electrical Engineers

ORIGINALLY

The Society of Telegraph Engineers

FOUNDED 1871

INCORPORATED BY ROYAL CHARTER 1921

EDITED BY P. F. ROWELL, SECRETARY

SAVOY PLACE, VICTORIA EMBANKMENT, LONDON, W.C.2

Telegrams: "VOLTAMPERE, PHONE, LONDON." Telephone: TEMPLE BAR 7676.

Vol. 75 DECEMBER, 1934 No. 456

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E. and F. N. SPON LIMITED, 57 HAYMARKET, LONDON, S.W.
ENGINEERS BOOK SHOP, 227 PARK AVENUE, NEW YORK.

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[*Continued on page (III) of Cover.*

THE TWENTY-FIFTH KELVIN LECTURE.

"ELECTRICAL PHENOMENA AT EXTREMELY LOW TEMPERATURES."

By Professor J. C. McLENNAN, D.Sc., LL.D., F.R.S.

(*Lecture delivered before* THE INSTITUTION *26th April*, 1934.)

INTRODUCTION.

With the liquefaction of the gas helium, and its final solidification by Prof. Keesom* on the 26th June, 1926, the last page might be said to have been written to a chapter of brilliant achievement in science; a chapter whose opening paragraphs record the experiments and discoveries of Michael Faraday at the Royal Institution in the early nineteenth century.†

It was Lavoisier, the great chemist, who suggested to his doubtless sceptical contemporaries that if the earth were cooled sufficiently, even the gaseous air above might take a liquid form, but many years were to pass before the liquefaction of gases was demonstrated in the laboratory. Sir Humphry Davy and his young assistant Faraday found that the gas chlorine, formed by heating its hydrate in a sealed tube, could be condensed to a yellow liquid. Ammonia, sulphuretted hydrogen, and hydrochloric acid gas, quickly yielded to their experimental skill, and by 1823 Faraday had installed at the Royal Institution what might truly be called a liquefaction plant.

Progress in both the technique and the range of application of such experiments was rapid. The little cylinders we use to recharge the soda-water siphons, and the "dry ice" or "snow" used extensively in hospitals and for commercial refrigeration purposes, have made us familiar to-day with carbon dioxide, normally a gas, in its liquid and its solid forms; but they were introduced to the world in 1834 by Thilorier. Faraday was quick to turn to advantage the new discoveries; by mixing carbon-dioxide snow with ether he obtained a freezing mixture, immersed in which his test tubes might be cooled to a temperature of $-110°$ C., or, on the commonly used Fahrenheit scale, 166 degrees below zero; a temperature far below any occurring naturally on the earth. A field of research full of new and strange possibilities opened up before the physicists and chemists of the day. Would even the gases of the atmosphere, oxygen and nitrogen, would hydrogen and the other gases that had so far resisted all attempts to liquefy them, yield to the new low temperatures now reached by science, or were they really "permanent" gases as so many thought? Thomas Andrews, the professor of chemistry at Belfast, tried to effect the liquefaction, and, like others before him, failed, yet made of his very failure a success. In one of the long-distinguished Bakerian lectures before the Royal Society he explained his experiments with carbon dioxide (his original apparatus is to-day in the South Kensington Museum), which showed that in the liquefaction of a gas not only the temperature but also the pressure to which it was subjected played an essential part. Here was the key to the locked door; unless the pressure exceeds a certain "critical pressure," and the temperature is below a certain "critical temperature," peculiar to the gas, we can never hope to liquefy it; cold allied to compression succeeds where the one alone fails.

The story then is one of triumph after triumph, as one gas after another fell before the advance of scientific achievement. Oxygen was liquefied by Olszewski in 1883, and two years later nitrogen and carbon monoxide had proved to be non-permanent gases after all, so that the "liquid air" of Lavoisier's dream had become an accomplished fact. The list of lowest temperatures as they were reached, reads like the records of athletic achievement; in both the next step is always harder to achieve than the one before. A new principle was applied to produce the cooling, a principle that is indeed the basis of our modern methods of refrigeration. Anyone who has used a bicycle pump must have noticed that compression of a gas produces heat and raises its temperature; that the converse is equally true is perhaps not so well known. If a gas under pressure below its inversion temperature is allowed to expand freely through a fine nozzle or if it is allowed to do mechanical work while expanding, it will cool, and may reach a temperature at which it liquefies. By an ingenious arrangement of the apparatus, the gas cooled by such a process is made to lower the temperature of the oncoming gas, which on expansion reaches a still lower temperature, until at last the liquid is produced. By such means as these, hydrogen was at length liquefied by Olszewski in 1892, and there remained of all known substances only the gas helium as yet uncondensed.

Hydrogen is a liquid at $-253°$ C., or only 20 degrees above what we call the absolute zero of temperature, but these remaining 20 degrees present difficulties of attainment vastly greater than 20 degrees of normal temperature. Practically every factor that conspires to prevent further cooling has here increased in importance. It is only by the use of the vacuum flasks invented by Dewar that the excess of heat from the surroundings is prevented; indeed, without his invention, all progress in liquefaction must have reached an early limit. Any foreign gas existing in the helium as an impurity must be removed; its presence would mean that the apparatus would soon be choked with solid substances, for at $-259°$ C. even hydrogen has solidified. It was at Leiden in 1908 in the laboratories of Prof. Kamerlingh Onnes that at length the goal was reached.

* See Bibliography, (1). † *Ibid.*, (2).

At a temperature of $-269°$ C., or about 4·2 degrees above absolute zero, the first drop of liquid helium fell into the receiving flask; very similar in appearance to a common drop of water, but the climax of a hundred years' achievement. Few in London have had an opportunity of seeing this rare and hardly-won liquid except those who were present at my lectures in June, 1932, and January, 1933, at the Royal Institution.

It is a long way from Michael Faraday's comparatively simple experiments to the operation of a modern liquid-helium plant, but just as to produce liquid helium we first make liquid air, then by its use cool the apparatus to make liquid hydrogen, and with this make possible the liquefaction of helium; just so has each achievement been built upon the work preceding it.

By reducing the pressure over liquid helium, still lower temperatures can be reached; and it was in this way that Keesom succeeded about a year ago in cooling liquid helium to an estimated temperature of about 0·71 degree above the absolute zero. In 1926 Keesom* also succeeded in demonstrating at Leiden the solidification of helium by applying high pressure to helium in the liquid state. Thus man has conquered, and every known substance has yielded to his will; at such temperatures as are now attainable, all the world can be solidified, and gases and liquids will exist no more.

Liquid helium is at present available for research in such centres as Leiden; Toronto; Berlin; Breslau; Washington; Berkeley, California; Oxford; and Cambridge.

Measurement of Temperatures.

It is possible by means of observations and an application of the gas laws to determine equations of state for helium that enable one to establish a temperature scale applicable over a range extending down to about 1·5° K. Below this temperature we are largely dependent on extrapolation. The vapour pressure of liquid helium enables us to reach the temperature 0·71° K., and the magnetic susceptibilities of certain salts can be used to tell us when such temperatures as 0·05° K. are reached.

For the study of properties of matter between the temperatures of 4·2° K. and 0·05° K. a liquid-helium cryostat is uniquely suitable. The temperature of the liquid helium can be modified by varying its equilibrium vapour pressure, and readings on the vapour-pressure can easily be made with an accuracy of at least $\frac{1}{100}$ degree. That this is so can be seen from the numbers recorded in Table 1.

Table 1.

Vapour Pressure of Liquid Helium.†

Vapour pressure	Temperature	Vapour pressure	Temperature
cm of Hg	°K.	cm of Hg	°K.
132·9	4·899	0·500	1·538
76·00	4·219	0·250	1·393
50·00	3·795	0·1000	1·237
25·00	3·218	0·0500	1·139
10·00	2·636	0·0250	1·055
5·00	2·298	0·0100	0·960
2·50	2·013	0·0050	0·899
1·000	1·714	0·0025	0·844

Liquid Helium.

Liquid helium is a light, colourless, mobile liquid. Its density varies with its temperature and with the pressure to which it is subjected. Under a pressure of 1 atmosphere and at a temperature of 4·2° K., it is 0·1252 or about one-eighth the density of water. A series of densities measured for liquid helium by Prof. and Miss Keesom* is given in Table 2. For each pressure to which it is subjected, liquid helium reaches a maximum density at a definite and characteristic temperature, known as the λ point. For a pressure of 1 atmosphere this temperature is 2·178° K., and for a pressure of 25 atmospheres it is 1·835° K. The corresponding maximum densities are respectively 0·1473 and 0·1757. The higher the pressure the lower is the λ point, and the greater the critical density.

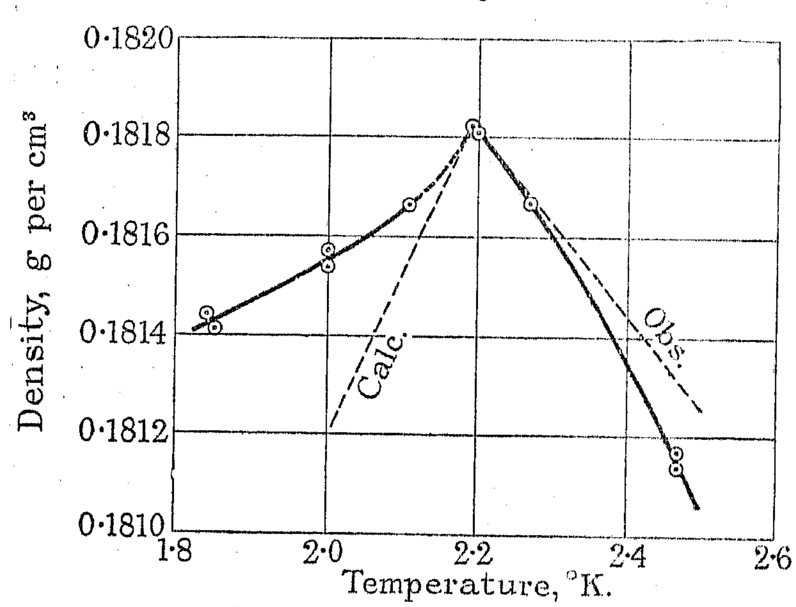

Fig. 1.

A curve of densities taken from a paper by Keesom† is shown in Fig. 1. This curve consists of two branches which meet at the λ point under a finite angle. Above this point the liquid is known as helium I, and below as helium II.‡ Immediately above the λ point the coefficient of expansion for temperature is positive and is given by $\alpha_1 = 0\cdot0222$ (deg.)$^{-1}$, and just below it is negative and given by $\alpha_{11} = -0\cdot0426$ (deg.)$^{-1}$. Helium I and helium II are both highly compressible.

A provisional determination made by Keesom and Clusius§ of the compressibility of liquid helium has given for χ at 2·71° K., a value of $7\cdot18 \times 10^{-3}$ cm² per kg for $p = 8\cdot87$ kg per cm². This result is interesting because it is the highest value obtained as yet for the compressibility of a liquid. The dielectric constant of liquid helium varies with temperature, and shows a discontinuity at the λ point. The specific heat of liquid helium under its saturated vapour pressure has been measured also by Prof. and Miss Keesom,‖ in the neighbourhood of 2·19° K., the λ point, with increments of

* See Bibliography, (1). † *Ibid.*, (4).

* See Bibliography, (5). † *Ibid.*, (6). ‡ *Ibid.*, (7). § *Ibid.*, (8). ‖ *Ibid.*, (9).

TABLE 2.

Density of Liquid Helium, in grammes per cm³.

°K	$p = 1$	$p = 5$	$p = 10$	$p = 15$	$p = 20$	$p = 25$	$p = 30$	$p = 35$ atm.
1·25	0·1462	0·1522	0·1584	0·1636	0·1681	0·1722		
1·50	0·1463	0·1524	0·1585	0·1638	0·1686	0·1728		
1·75	0·1465	0·1527	0·1591	0·1646	0·1696	0·1743		
1·80	0·1465	0·1528	0·1592	0·1648	0·1699	0·1750	0·1796	
1·90	0·1466	0·1531	0·1597	0·1655	0·1711	0·1757	0·1795	
2·00	0·1468	0·1534	0·1604	0·1666	0·1713	0·1756	0·1794	0·1829
2·10	0·1470	0·1540	0·1609	0·1665	0·1712	0·1755	0·1793	0·1828
2·20	0·1472	0·1540	0·1608	0·1663	0·1710	0·1753	0·1790	0·1826
2·25	0·1471	0·1539	0·1606	0·1662	0·1709	0·1752	0·1789	0·1824
2·50	0·1460	0·1530	0·1600	0·1655	0·1703	0·1745	0·1783	0·1818
3·00	0·1424	0·1505	0·1579	0·1637	0·1686	0·1730	0·1768	0·1803
3·50	0·1370	0·1469	0·1551	0·1615	0·1666	0·1712	0·1751	0·1786
4·00	0·1292	0·1421	0·1518	0·1587	0·1644	0·1691	0·1732	0·1768
4·20	0·1252	0·1399	0·1502	0·1575	0·1634	0·1682	0·1724	0·1761
	λ curve						Solidification curve	
ρ	0·1473	0·1541	0·1610	0·1666	0·1714	0·1757	0·1796	0·1831
T	2·178	2·125	2·058	1·990	1·915	1·835	1·757	1·920

0·01 to 0·02 degree. The results indicate that the specific heat has a maximum value of about 3·00 at 2·19° K., and falls down to 1·1 certainly within 0·02

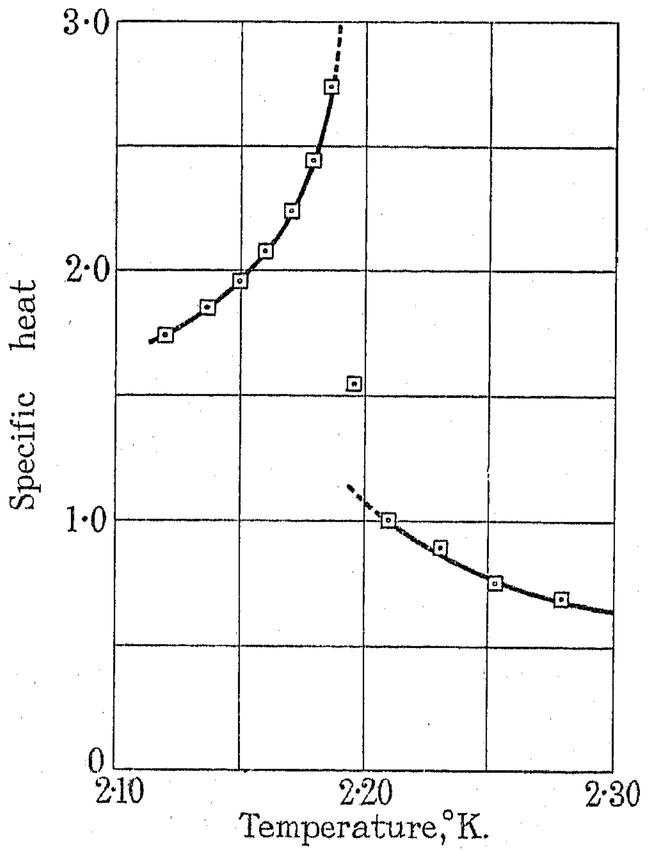

FIG. 2.

degree and probably within 0·002 degree. This discontinuity in the value of the specific heat is shown clearly by the curve in Fig. 2, where the ordinates are expressed in calories per deg. K. per gramme.

From these and other characteristics of liquid helium it is clear that in helium I and helium II we have two phases, each possessing clearly defined characteristic properties that will bear further investigation. The heat conductivity, the viscosity, the refractivity, as well as the structure and composition, for example, of liquid helium, might be studied with advantage. It is probable that phases similar to those of helium I and helium II will be found to characterize liquefied neon, argon, krypton, and xenon, and as these are more easily obtainable from a physical point of view than liquid helium, they might well be given consideration.

SOLIDIFIED HELIUM.

For what information we possess regarding the solidification of helium, we are indebted to Keesom and Simon, with their associates. As already mentioned, helium was first solidified by Keesom* in 1926. Kamerlingh Onnes had attempted to solidify liquid helium by reducing, by means of powerful pumps, the vapour pressure to which it was subjected. He succeeded in reaching a temperature of 0·8° K. but without obtaining any evidence of solidification. Keesom, reversing the process, succeeded in obtaining solidification by subjecting liquid helium to a series of high pressures. At a temperature of 1·10° K. a pressure of 26 kg per cm² sufficed, but at a temperature of 4·2° K. a pressure of 145 kg per cm² was found to be necessary. Simon† and his associates showed that at 800 atmospheres the melting point of solid helium was 12° K., and that at 5 600 atmospheres the melting point was 40° K. By extrapolation he estimated that to solidify helium at a

* See Bibliography, (1).

† *Ibid.*, (10).

temperature of 100° K. (or − 173·2° C.) a pressure of approximately 22 000 atmospheres would be required.

The heat of fusion of solid helium is 6·75 calories per gramme-atom at 4·0° K., and 5·1 calories per gramme-atom at 3·4° K. The density in equilibrium with the liquid phase at 4·0° K. is 0·23, and at 3·6° K. it is 0·22. The compressibility, according to Kaischew and Simon, is approximately $1 \cdot 5 \times 10^{-3}$ per atmosphere at 3·7° K. and 115 atmospheres.

New Methods.

(i) *Liquefaction of Helium.*

For the liquefaction of helium, the method adopted until recently involved the use of the Joule–Thomson effect. When it becomes desirable, however, to produce liquid helium in small quantities and at a low cost,

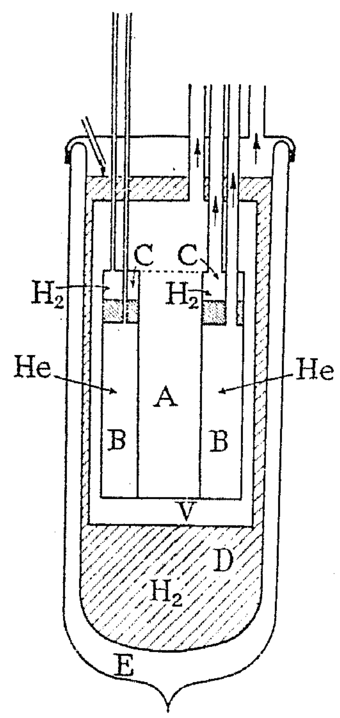

Fig. 3.—Apparatus of Simon and Mendelssohn.

apparatus of the type devised by Simon and Mendelssohn may be used. It is this type of equipment that is in use at Oxford.* The method, which is a discontinuous process, involves the compression of helium to about 150 atmospheres in the annular space B between the two concentric cylinders shown in Fig. 3. The experimental material to be studied is placed in the metal container A, which is immersed in liquid hydrogen boiling in D under reduced pressure.

In the process the container V is at first filled with gaseous hydrogen or helium in order to provide a conducting medium to bring the inner cylinder B containing the compressed helium to 15° K., the temperature of the liquid hydrogen. For additional cooling, liquid hydrogen boiling under reduced pressure is held in the annular space C. When temperature equilibrium is attained the container V is evacuated with a powerful diffusion pump, and the helium compressed in B is allowed to expand. In this process, about one-half of the helium liquefies and serves to cool the two cylinders B and the material in them to the temperature of liquid helium.

* See Bibliography, (12).

By another process, a separate container within the chamber B but not shown in the figure, is filled with charcoal, zeolithe, chabasite, or silica-gel, and allowed to absorb helium while temperature equilibrium is being established, the chambers A and B being again insulated thermally as before by the evacuation of the space V. The helium absorbed by the charcoal is quickly pumped off and cooling follows. This lowering of the temperature liquefies a part of the helium in the chamber B, and the material in A is consequently cooled to liquid-helium temperatures.

Methods for producing a lowering in temperature under very special conditions have recently been brought forward that involve the adiabatic expansion of solid helium and of liquid helium I, i.e. liquid helium above the λ point. In order to bring about a cooling effect with

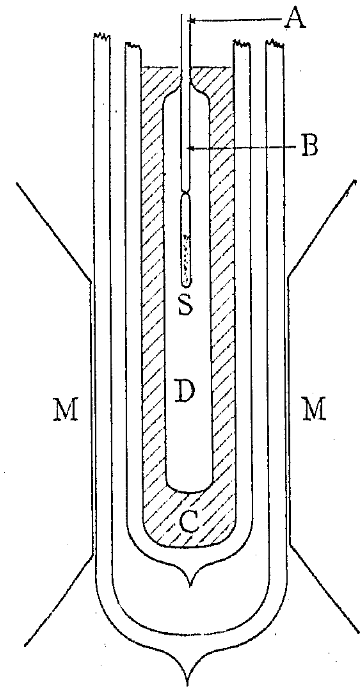

Fig. 4.—Apparatus used by de Haas to produce the lowest temperatures by demagnetization of salts.

liquid helium II, it would appear that adiabatic compression rather than expansion would be required.

(ii) *Cooling by Demagnetization.*

What promises to be a procedure of great importance in research at the lowest temperatures is based on the use of the cooling effect obtainable under certain conditions by adiabatic demagnetization. Debye* and also Giauque† in 1926 showed that it would be possible to get an effect of a measurable order with paramagnetic salts if the initial temperature were sufficiently low. Giauque and Clark‡ even suggested that the temperature obtainable in this way might be extremely low.

Recently the method was tested by de Haas, Wiersma, and Kramers,§ and found to be highly efficient. A sketch of the apparatus used is shown in Fig. 4. The sample of paramagnetic salt S to be magnetized and demagnetized was held in a small glass tube B, which formed part of a small Dewar flask that was suspended from a rod and attached to one arm of a balance. The whole apparatus was placed with the salt suspended between the poles

* See Bibliography, (13). † *Ibid.*, (14). ‡ *Ibid.*, (15). § *Ibid.*, (16).

of an electromagnet and occupying the region where $H\partial H/\partial x$ had a maximum value. The suspended Dewar flask was surrounded, as shown in the diagram, with liquid helium boiling at a temperature of 1·26° K. A small amount of helium gas having a pressure of 10^{-7} mm of mercury was left in the space D to give thermal contact with the liquid helium in the outer vessel C. In the initial experiments a field as high as 30 000 gauss was maintained by the magnet until the weight of the system suspended from A indicated that an equilibrium state had been reached. One could be certain then that under these conditions the specimen S was at the temperature 1·26° K. and that it was exhibiting the magnetic susceptibility corresponding to that temperature. When these conditions obtained and the magnetic field was suddenly reduced to a fixed low value, of 1 000 or 500 gauss, for example, the adiabatic demagnetization of the salt S ensued, and the lowering of its temperature followed. The salt itself indicated by its susceptibility the temperature reached as a result of the demagnetization, for the curve showing the relation between the pull of the field and the temperature of the specimen had been previously obtained for a range of temperature from 7·2 to 1·3° K. and extrapolated linearly to lower temperatures. The value of the lowest temperature reached as a result of the demagnetization was given by the value of the pull of the field (1 000 or 500 gauss) immediately following demagnetization. Conduction of heat to the specimen from the surrounding liquid helium caused the temperature gradually to rise and the pull to lessen owing to its susceptibility falling off. A curve showing this decrease in pull is given in Fig. 5. This curve calls attention to one defect in the method. It takes, it will be seen, a long time for equilibrium to be reached. This makes the taking of measurements rather tedious, for it operates in both the initial and final stages of the experiment.

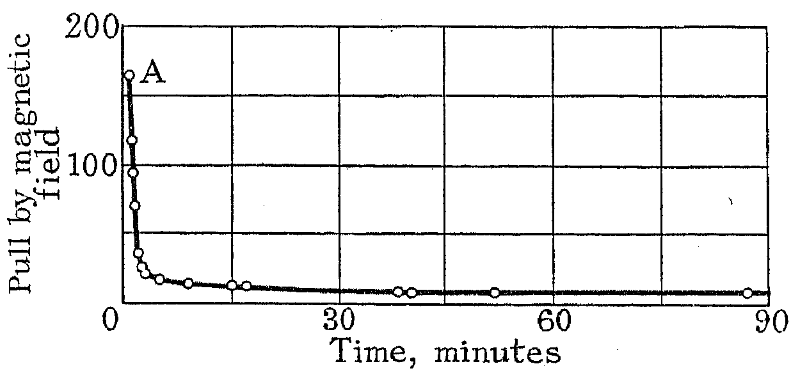

FIG. 5.—Example of temperature measurement by force exerted on a paramagnetic salt in a magnetic field. Curve shows increase of temperature of salt after demagnetization from $T = A$ to $T = 2 \cdot 16°$ K.

The salts used so far have been cerium fluoride [CeF_3], dysprosium ethyl sulphate [$Ds(C_2H_5SO_4)_3 9aq.$], cerium ethyl sulphate [$Ce(C_2H_5SO_4)_3 9aq.$], and potassium-chrome alum. With cerium fluoride a temperature of 0·13° K. was reached, with dysprosium ethyl sulphate 0·12° K., with cerium ethyl sulphate 0·085° K., and with potassium-chrome alum 0·03° K., the last-mentioned being the lowest temperature ever attained and measured. It may be added that with the use of manganese ammonium sulphate Kurti and Simon* reached a temperature of 0·1° K.

LOW-TEMPERATURE ELECTRICAL CONDUCTIVITY OF METALS.

General.

It is of interest to find that the solutions of many problems connected with the conduction of electricity through metals are likely to be reached through low-temperature research.

The classical experiments of Dewar and Fleming† made in 1893 on the electrical conductivity of metals cooled to very low temperatures by means of liquefied gases, including air and hydrogen, come to mind. These yielded results suggesting that the electrical resistances of all pure metals would vanish at the absolute zero of temperature.

This suggestion, however, proved to be wrong, for in 1911, Kamerlingh Onnes at Leiden, while carrying out researches at low temperatures with the aid of liquefied helium, discovered that mercury, when cooled down and solidified with liquid helium, suddenly and abruptly at about 4·2° K. became what is now designated a super-conductor of electricity. At temperatures below 4·2° K., mercury offers no measurable resistance to the passage of a current. Currents of electricity started in a ring of a metal in the super-conducting state will continue apparently undiminished in intensity while the metal is in that state. The duration of these persistent induced ring currents seems to be limited only by the length of time the cooling agent, liquid helium, will last. In the course of a lecture on super-conduction in metals, delivered on the evening of the 3rd June, nearly two years ago, at the Royal Institution, I exhibited to the audience a closed ring of lead immersed in liquid helium and carrying a current of more than 200 amperes. The current had been started in the super-conducting lead ring some 6 hours earlier in the afternoon by Prof. Keesom in Leiden, and had persisted undiminished in intensity while being transported in liquid helium by aeroplane from Leiden to London by Colonel the Master of Sempill (now Lord Sempill).

Super-Conducting Metals.

Other metals in addition to mercury and lead that exhibit the super-conducting property if made sufficiently cold are tin, indium, vanadium, aluminium, zinc, gallium, thallium, tantalum, titanium, thorium, and niobium. The transition temperature for the passing of a metal from the ordinary conducting to the super-conducting state is not a constant but varies with the metal. For mercury it is 4·22° K., for lead, 7·2° K., tin, 3·7° K., tantalum, 4·4° K., thallium, 2·37° K., indium, 3·37° K., gallium, 1·05° K., thorium, 1·5° K., titanium, 1·75° K., niobium, 9·2° K., vanadium, 4·3° K., aluminium, 1·14° K., zinc, 0·79° K., and cadmium, 0·6° K.‡

Vanadium is especially interesting because next to aluminium and titanium it is the super-conductor with the smallest atomic weight, and unlike the others it has a convenient transition temperature.

Special investigation has shown that silver, magnesium, and tungsten, are still not super-conducting at

* See Bibliography, (17). † *Ibid.*, (18). ‡ *Ibid.*, (17).

0·74° K.; and bismuth, iron, and nickel, not at 0·75° K. Lead remains super-conducting still at 0·75° K.

Alloys and Chemical Compounds.

Some alloys and chemical compounds of the metals also exhibit the super-conducting property. Copper sulphide, for example, does so, though neither of the constituent elements is a super-conductor. The nitrides and carbides, borides and silicides of several of the metals —such, for example, as those of molybdenum, tungsten, tantalum, zirconium, and niobium—are also super-conducting at sufficiently low temperatures.

The addition of metals of the bismuth group to super-conducting metals has been found, speaking generally, to raise their transition temperature. Bismuth added to lead raises the transition temperature from 7·2° to 8·8° K.; carbon raises that of niobium from 9·2° to 10·1° K. Gold alloyed with bismuth becomes super-conducting at 1·94° K., whereas neither constituent alone becomes super-conducting even at the lowest temperatures obtainable.

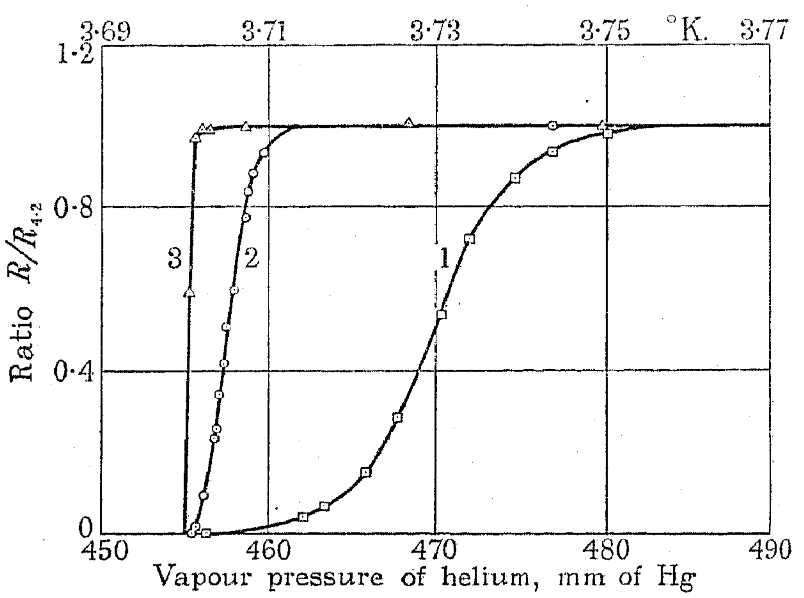

FIG. 6.

With pure metals the transition from the ordinary conducting to the super-conducting state generally occurs within a tenth or at most a few hundredths of a degree. With impure metals, alloys, or chemical compounds, the transition is not generally so rapid. The temperature interval for the transition stage has been found by de Haas* in the case of tin to be a minimum when the crystalline state of the metal is of the simplest type. This is illustrated by the curves in Fig. 6, where Curve 1 is the transition curve for a wire of poly-crystalline tin, Curve 2 is for a tin wire made up of several large crystals, and Curve 3 is for a wire made of a single crystal of tin. In the transition stages, for most of the metals the variation of resistance can be readily followed by observing the vapour pressure of the liquid in which the metal is immersed. In the case of liquid helium, a variation in vapour pressure of about 40 mm of mercury corresponds to about 0·1 deg. C.

Recently McLennan, Allen, and Wilhelm,† in making a study of various alloys of the silver-tin, gold-tin, and gold-lead systems, found three outstanding features to characterize the results. First, in alloys with the super-conducting elements it was observed that gold and silver produced an effect on the transition temperature opposite to that produced by bismuth, antimony, and arsenic. When one observes alloys containing the latter metals, one finds usually a pronounced elevation of the super-conducting temperature, while in alloys with gold and silver one finds an equally pronounced depression of that temperature. Secondly, it was noted that a binary alloy system composed of a super-conductor and a non-super-conductor does not necessarily have a unique transition temperature. Thirdly, it was found that with the alloy systems silver-tin, gold-tin, and gold-lead, the transition temperatures were higher for eutectic mixtures than for chemical compounds of the two metals constituting the alloys. The data compiled in Table 3 will serve to illustrate these points. The element silver and the compound Ag_3Sn, it will be seen, have not been found to be super-conductors at any temperature reached up to the present.

It has been shown by Meissner* in an examination of the alloy systems In-Pb, In-Tl, Pb-Bi, Pb-Hg, Pb-Tl, Tl-Sn, and of other systems as well, that the super-conducting transition temperature of an alloy is a continuous function of the concentration. From an extensive investigation of the thallium-tin system of alloys, J. F. Allen† has recently found some interesting features connected with the eutectic region. Both the transition temperature and the transition interval become a minimum for the eutectic. The transition interval increases from zero for pure tin to 1·3 deg. for 78 per cent tin, and then decreases to 0·8 deg. at the eutectic. The interval grows to 2·5 deg. again near 40 per cent tin and again shrinks to 1·2 deg. as the region of solid solution is approached. X-ray examination of these Tl-Sn alloys shows that both of the components possess maximum dimensions at the eutectic, and this indicates a close relation between super-conductivity and crystal structure.

From the work of Meissner, de Haas, and others, and from the X-ray measurements of Solomon and Morris Jones‡ on the Pb-Bi alloy system, a connection appears to exist between the super-conducting transition temperature and the dimensions of the crystal lattice. There are indications that the electrostatic field of force of the lattice is probably a fundamental factor in deter-

TABLE 3.

Tin-Silver alloys.

Substance	Mixture	Percentage of tin	Transition temperature
			° K.
Sn	Pure	100	3·76
$Ag+Sn$	Eutectic alloy	96	3·52
Ag_3Sn+Sn	Eutectic alloy	50	3·57
Ag_3Sn+3 per cent Sn	Mixture	30	2·3
Ag_3Sn	Compound	27	—
Ag	Pure	0·0	—

* See Bibliography, (19). † *Ibid.*, (20).

* See Bibliography, (21). † *Ibid.*, (22). ‡ *Ibid.*, (23).

mining whether a substance will become a super-conductor or not.

Mechanical Strains and Thermal Dilatation.

The application of mechanical stresses such as those of torsion and tension raises the transition temperature of a super-conducting metal, but observations made on the thermal dilatation of a lead rod showed no discontinuity when its temperature was lowered as it passed through the transition temperature, 7·2° K., from the ordinarily conducting to the super-conducting state.

Action of a Magnetic Field.

The application of a magnetic field delays the appearance of super-conductivity and causes it to appear in a metal at a lower temperature than normally.

If a metal in the super-conducting state be subjected

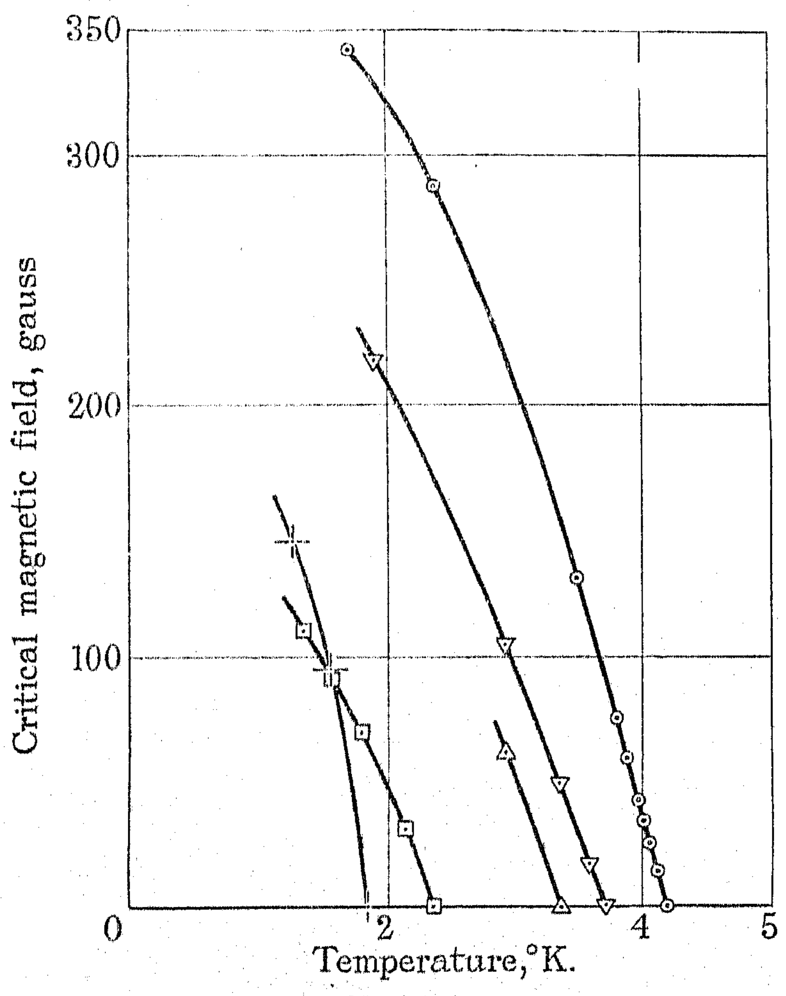

FIG. 7.

Hg. Sn. In. Tl. Au_2Bi.

to a gradually increasing magnetic field, a critical field strength is reached at which electrical resistance reappears in the metal. The strengths of the critical fields required for different super-conductors vary; for example, an alloy of bismuth and lead at 1·91° K. requires a magnetic field of 26 700 gauss to restore the property of electrical resistance, while metallic tin at about the same temperature requires a field of only 220 gauss. In Fig. 7, curves are shown which give the characteristic values of the critical magnetic fields* as a function of temperature for a number of super-conducting metals.

Since the electrical resistance of super-conducting metals is zero, no heat is produced when electrical currents are passed through them. Currents of high intensity can therefore be passed through super-conducting wires of small diameter without melting them. Electric currents of more than 1 000 amperes have been so obtained in wires of small cross-section. The factor that imposes a limiting value upon the current strength is the magnetic field set up in the wire by the current itself. A critical value is reached when resistance is restored to the wire by the magnetic field.

Owing to the fact that metals in the super-conducting state have no electrical resistance, currents of electricity induced in rings of metals in this state will persist with undiminished intensity so long as the metals remain super-conducting. So far, it has been found impossible to detect with instruments of precision any diminution in the intensity of ring currents in super-conductors even after the lapse of a period so long as 13 hours.

Recently some experiments were carried out by McLennan, Allen, and Wilhelm,* on the intensities of persistent currents of electricity induced in rings having the same dimensions and made of lead, of tin, and of tantalum, brought into the super-conducting state by the use of liquid helium. The currents in the rings were induced by the magnetic field provided by electric currents established in a circular coil of wire placed,

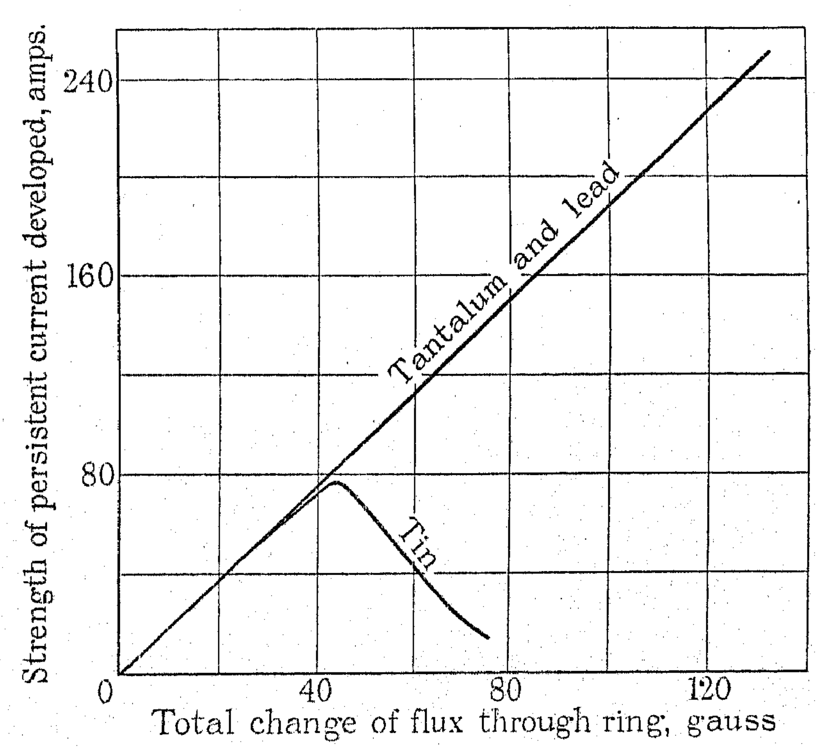

FIG. 8.

in turn, coaxial with and close to each of the super-conducting rings. The results of these experiments are represented by the graph shown in Fig. 8. It was found that, for the weaker magnetic fields, equal changes of flux produced currents of equal magnitude in each of the three super-conductors. The magnitude of the persistent current developed depended not on the substance of the super-conducting ring but only on its dimensions and on the magnitude and form of the inducing magnetic field.

The case of tin is very interesting, since the values of the current in it agreed with those of the current in the others only up to fields of about 30 gauss. For inducing fields higher than this amount the strength

* See Bibliography, (24).

* See Bibliography, (25).

of the persistent current dropped off. Above this point, then, part of the ring must have been in a magnetic field, the strength of which had reached the critical value where resistance reappeared, i.e. an inner layer of the ring must have become non-super-conducting. As the field was increased above this point, one can suppose that the outside super-conducting portion of the ring became thinner and thinner until finally the whole ring became conducting only in the ordinary sense.

The fact that the same flux engenders the same persistent current in different super-conducting metals having the same size and form follows from an application of the equation $Ldi/dt = dB_A/dt$, or $i = B_A/L$. For rings of the same dimensions, the self-inductances would be identical; and in the super-conducting state the resistances of the three metals would be vanishingly small. Self-inductance and zero resistance are the two

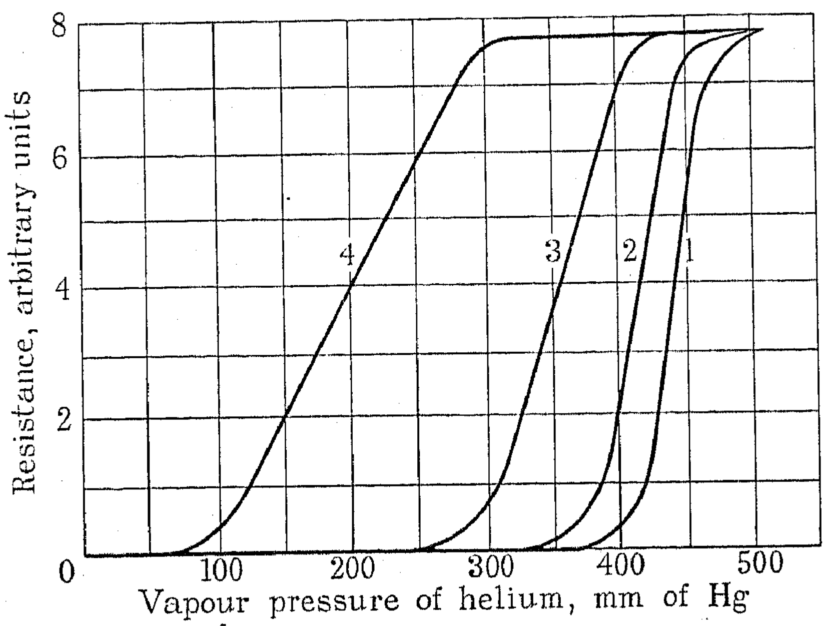

FIG. 9.—Lowering of transition temperature with increase of current.

(100 mm pressure ≡ 2·64° K.; 250 mm ≡ 3·22° K.; 500 mm ≡ 3·79° K.)

Tin on constantan: Curve 1, 50 milliamps. (d.c.). Curve 2, 100 milliamps. (d.c.). Curve 3, 200 milliamps. (d.c.). Curve 4, 500 milliamps. (d.c.).

factors that make the magnitude of the induced current in different super-conductors the same.

Looking at the matter in another way, we see that the induced currents in the three super-conductors must be the same since the magnetic field of the persistent current must be equal in magnitude and distribution, but opposite in direction, to the flux of the exciting field.

In his experiments with mercury and with thin films of tin, Onnes found that an increase in the current through the specimen studied lowered the transition temperature. Curves which illustrate this point are shown in Fig. 9.* They were plotted from measurements made at Toronto on the conductivity of tin-coated wires at various temperatures. This lowering of the transition temperature, as already indicated, was probably due to the magnetic field set up by the current through the specimen, since the application of a magnetic field to the region in which the specimen is placed has the effect of lowering the transition point. By agreement the accepted transition point is now generally defined as the temperature at which super-conductivity sets in when the current through the conductor is small.

Onnes was able to show that a finite resistance was restored to a specimen exhibiting super-conductivity when the current through it was raised to several hundred amperes. This point was cleared up when Silsbee* showed that the current which restored the resistance of the specimen studied produced a magnetic field in the wire equal to the critical magnetic field for the substance.

Specific Heats of Super-conducting Metals.

The specific heat of tin has been measured by Keesom and Kok† between the temperatures 3·741 and 3·505° K. In passing from above the transition point (3·7° K.) to a point below it, an abrupt rise in the specific heat was observed. It was found that the atomic heat increased from 0·0054 to 0·0078 calorie per deg. K. The results of the measurements of the specific heat are shown in Fig. 10.

Observations were also made by the same investigators on the specific heats of thallium between 1·3° and 4·2° K. With this metal also an increase in the atomic heat amounting to 0·00148 calorie per deg. K. was obtained in going from just above the transition point (2·37° K.) to a point just below it. Recently Keesom and Kok made calorimetric experiments with thallium in connection with the transitions in a number of constant magnetic fields from the super-conducting to the non-super-conducting state. A definite latent heat was measured for each field. The results seem to indicate that the transition from the super-conducting to the non-super-conducting state can be treated thermodynamically as a reversible process.

Heat Conduction in Metals at Low Temperatures.

Though the experiments are difficult to arrange and to carry out, de Haas and Bremmer‡ have succeeded at Leiden in measuring the conduction of heat at low temperatures by the super-conducting metals lead, tin, indium, and the lead-thallium alloy $Pb\text{-}Tl_2$. With all of them the thermal resistance fell to a minimum value as the temperature was lowered. With lead and tin the temperature corresponding to the increase in thermal resistance was slightly over 9° K. With indium it was 18·3° K., and with $Pb\text{-}Tl_2$ it was a higher value still. In the super-conducting region for all of them the thermal resistance rapidly increased with decreasing temperatures. A characteristic curve illustrating the observations made with lead is shown in Fig. 11.

The observations made with tin, both without and with the application of a magnetic field, are represented by the curves in Fig. 12. From these it will be seen that in the super-conducting region, i.e. below 3·7° K., the thermal resistance was lowered when the magnetic field was applied. This would seem to show that when a metal becomes super-conducting some constituent of it which is present at higher temperatures is no longer available for functioning in the conduction of heat by the metal.

* See Bibliography, (26).

* See Bibliography, (27). † *Ibid.*, (28). ‡ *Ibid.*, (29).

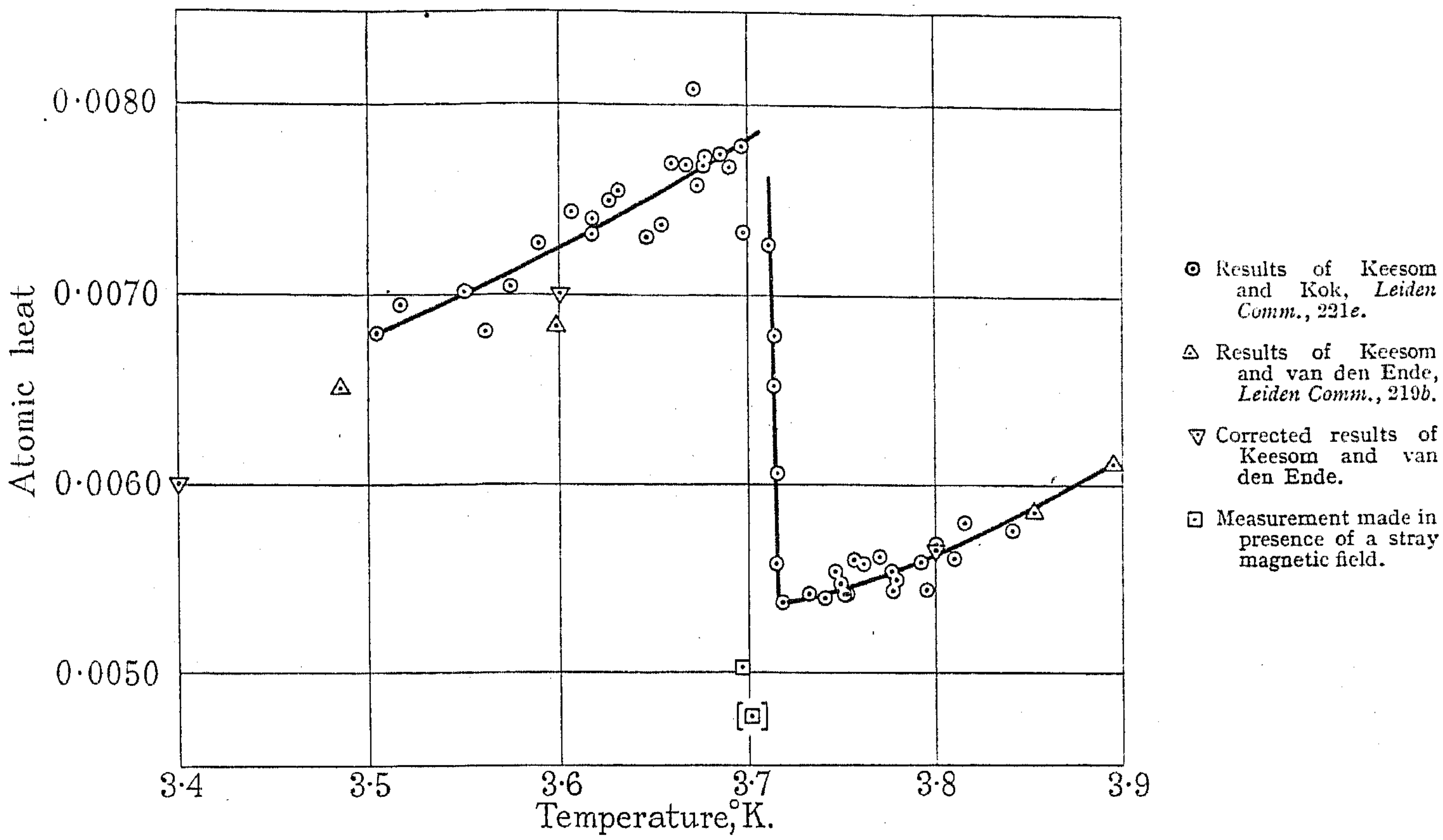

FIG. 10.

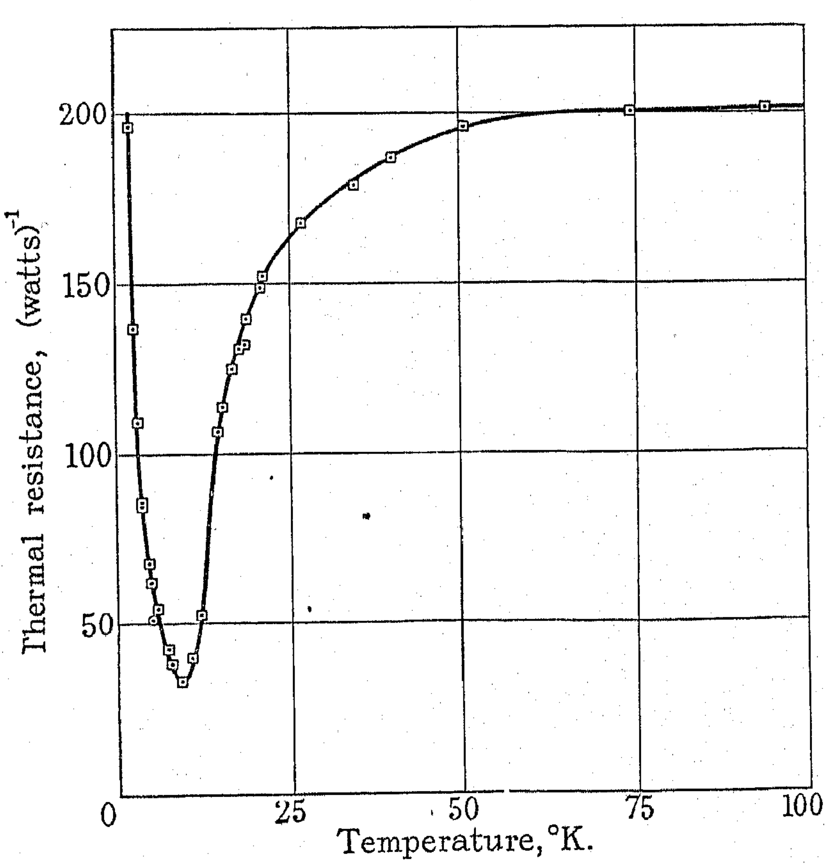

FIG. 11.

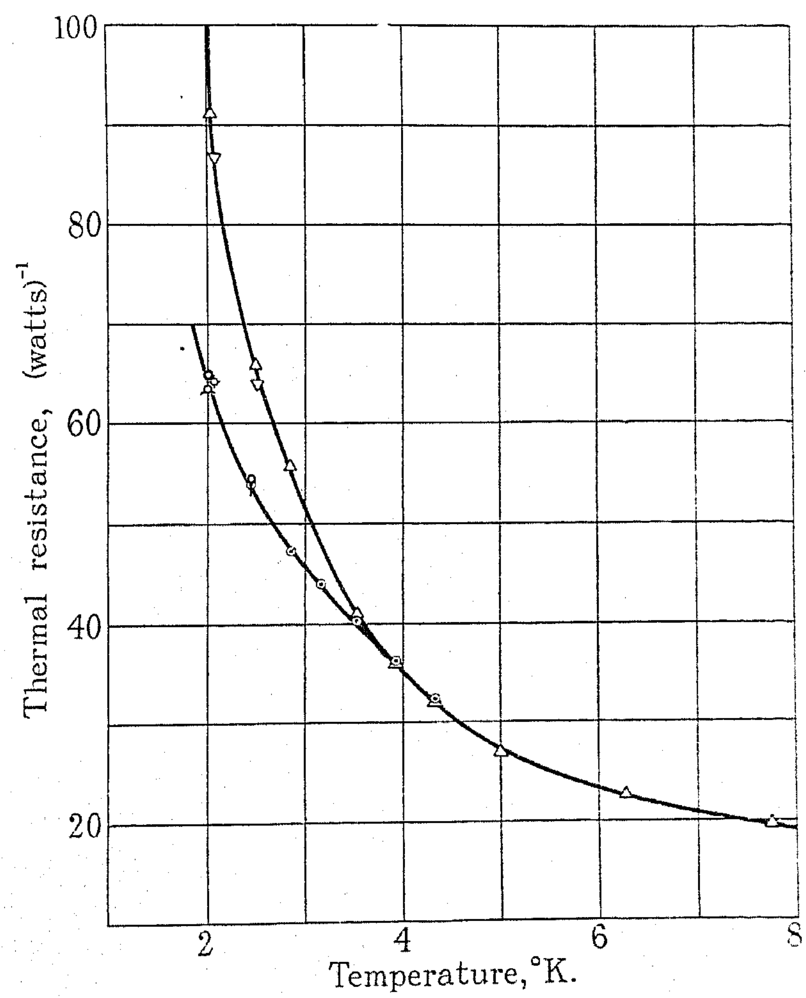

FIG. 12.

192·6 gauss.
257 gauss.
638 gauss.
428 gauss.
244 gauss.
0 gauss.
74·9 gauss.

Magnetic Properties of Super-conductors.

Meissner and Ochsenfeld* recently discovered that when tin, which is feebly paramagnetic, and lead, which is feebly diamagnetic, were placed in a magnetic field of small intensity and gradually cooled to very low temperatures they suddenly at the transition point assumed zero magnetic permeability or a diamagnetic susceptibility of $-1/(4\pi)$. This discovery has been confirmed by Mendelssohn and Babbett† at Oxford and by Burton‡ and his collaborators at Toronto. In the Toronto experiments a hollow cylinder of tin was used as the super-conducting body. It is shown, with dimensions inscribed, in Fig. 13. The cylinder was placed with its axis perpendicular to the magnetic field. Coil No. 1 was wound round one side of the cylinder, Coil No. 2 was placed inside the hollow cylinder, and Coil No. 3 was placed near the surface of the cylinder with its plane perpendicular to the field. Coil No. 4 was wound so as to enclose the whole cylinder in the plane of the coil, and No. 5 was placed at the outer surface of the cylinder with its plane perpendicular to the applied magnetic field.

According to the results of Meissner and Ochsenfeld, which are illustrated by the configuration of the magnetic lines of force in Figs. 14 and 15, one would expect—when the temperature of the tin cylinder was taken through the transition point to a temperature definitely below the super-conducting temperature—to observe the following: In Coil 1, a decrease to zero flux; in Coil 2, no change in flux; in Coil 3, an increase of twice the intensity of the applied field; in Coil 4, a decrease in flux due to the wiping-out of the magnetic flux in tin; in Coil 5, a decrease to zero flux. The search coils in the Toronto experiments were arranged to be connected directly to a flux meter. The tin cylinder was passed from the super-conducting to the non-super-conducting state as desired by simply altering the vapour pressure of the liquid helium in which the tin cylinder was immersed.

It was found that as the tin cylinder was taken from above the transition temperature to below it, Coil 1 showed a decrease of 90 per cent in the flux; Coil 2 showed a slight increase up to 10 per cent; Coil 3 showed an increase of 25 per cent; Coil 4 a decrease of 30 per cent, and Coil 5 a decrease of from 20 to 25 per cent. It should be noted that Coil 3 projected out about 5 mm from the surface of the cylinder, where there was undoubtedly a magnetic field of high gradient, and also that Coil 5 of necessity enclosed a considerable space where the field was not theoretically reduced to zero but only relatively weakened. The field strengths used were approximately 30, 150, and 200 gauss.

New Magnetic Test for Super-conductivity.

It is at once apparent that Meissner and Ochsenfeld by their discovery have provided a magnetic effect that can be used to make a decisive test for the appearance of super-conductivity. Burton and his associates at Toronto have applied it with interesting results in a new study of the alloy known as Wood's metal. As far as former super-conductivity measurements on this alloy are concerned one element alone of the alloy might have been responsible for the super-conductivity observed, with the other elements remaining in the non-super-conducting state. If, however, on applying the new test it were found that the magnetic field disappeared for the complete volume of the alloy, it would mean that the alloy as a whole became super-conducting. This complete disappearance of the flux was actually observed with Wood's alloy. The exploring coils, it may be added, were embedded in the molten metal (melting point 65° C.) and remained there when the alloy was cooled to its transition temperature. Wood's alloy, it is well known, has a constitution of 50 per cent bismuth, 25 per cent lead, 12·5 per cent tin, and 12·5 per cent cadmium.

The method is also being applied to a study of alloys that contain a number of phase constituents, with a view to determining the temperatures at which each of the different phases become super-conducting.

In another experiment carried out by Burton* at Toronto the magnetic-field test was used to examine the super-conductivity of an emulsion of mercury and lard. A microscopic examination of the emulsion indicated a surprising uniformity in the size of the globules of mercury (of the order of 10^{-5} cm). The emulsion was found to be quite non-conducting electrically at ordinary temperatures. At the lowest temperatures three tests were made, namely (1) pure mercury, (2) with the mercury emulsion, and (3) with pure lard.

An exploring coil was embedded in each of the matrices at room temperature, so that when the alloy cooled down and was frozen the coil was completely embedded. The amount of mercury in the emulsion was almost 50 per cent by volume. When the three substances were cooled down in a constant magnetic field the following results were obtained: (1) Magnetic flux completely disappeared as the temperature passed the mercury transition point. (2) A reduction in the flux of between 30 and 40 per cent. (3) No change in the flux.

These results showed that mercury can exhibit the super-conducting property even when it is in the form of very small globules 10^{-5} cm in diameter.

Super-conductivity with Rapidly Alternating Electric Fields.

The results of some of the experiments on super-conductivity suggest that an orientation or re-orientation of one or more of the constituents of the conducting metals takes place when the transition temperature is reached. As "times of relaxation" are generally associated with orientation effects, it was natural to investigate the phenomenon of super-conductivity by the use of rapidly alternating electric fields.

Absorption of Beta Rays.†

In one of these researches the absorption of β-rays by a thin sheet of lead was investigated when the lead was gradually cooled from a temperature a few degrees above to a few degrees below the critical transition temperature of 7·2° K. The β-rays used were those

* See Bibliography, (30). † *Ibid.*, (31). ‡ *Ibid.*, (32).

* See Bibliography, (33). † *Ibid.*, (34).

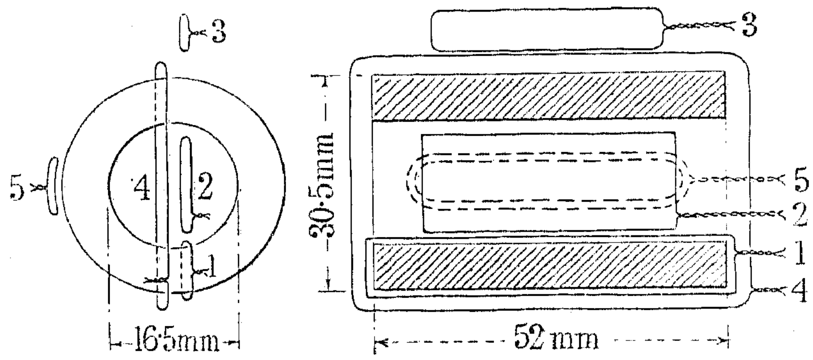

FIG. 13.

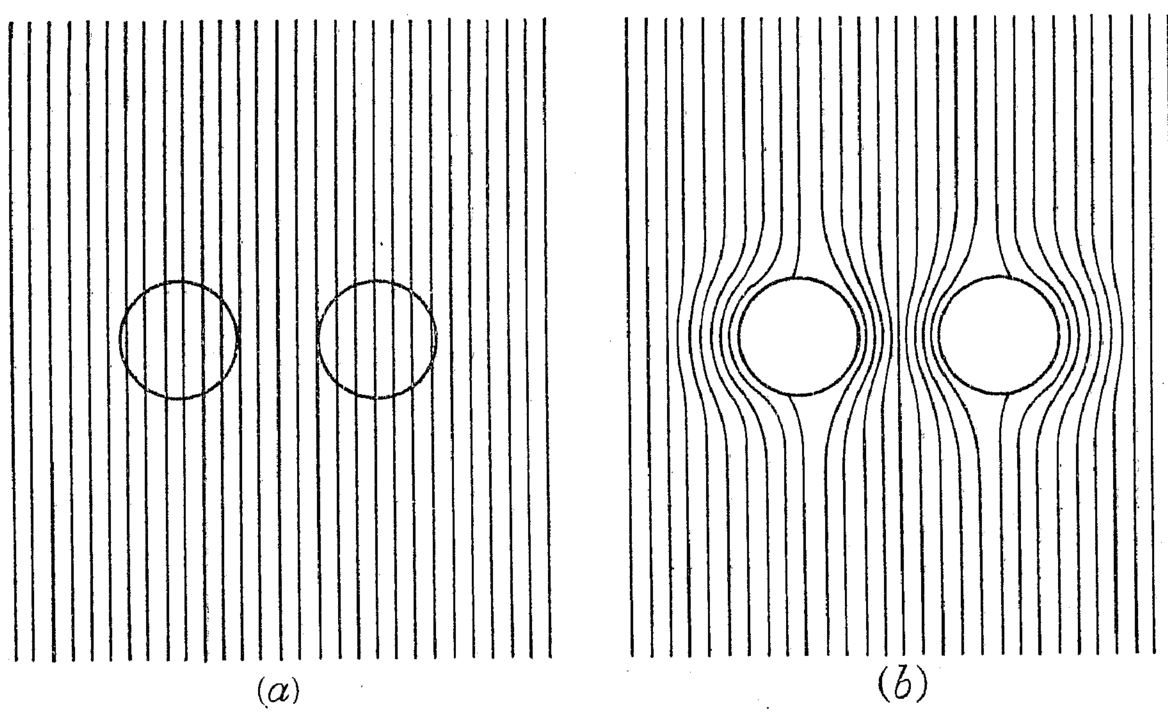

FIG. 14.—Parallel cylinders of tin in a magnetic field.
(a) $T > 3{\cdot}7°$ K.
(b) $T < 3{\cdot}7°$ K.

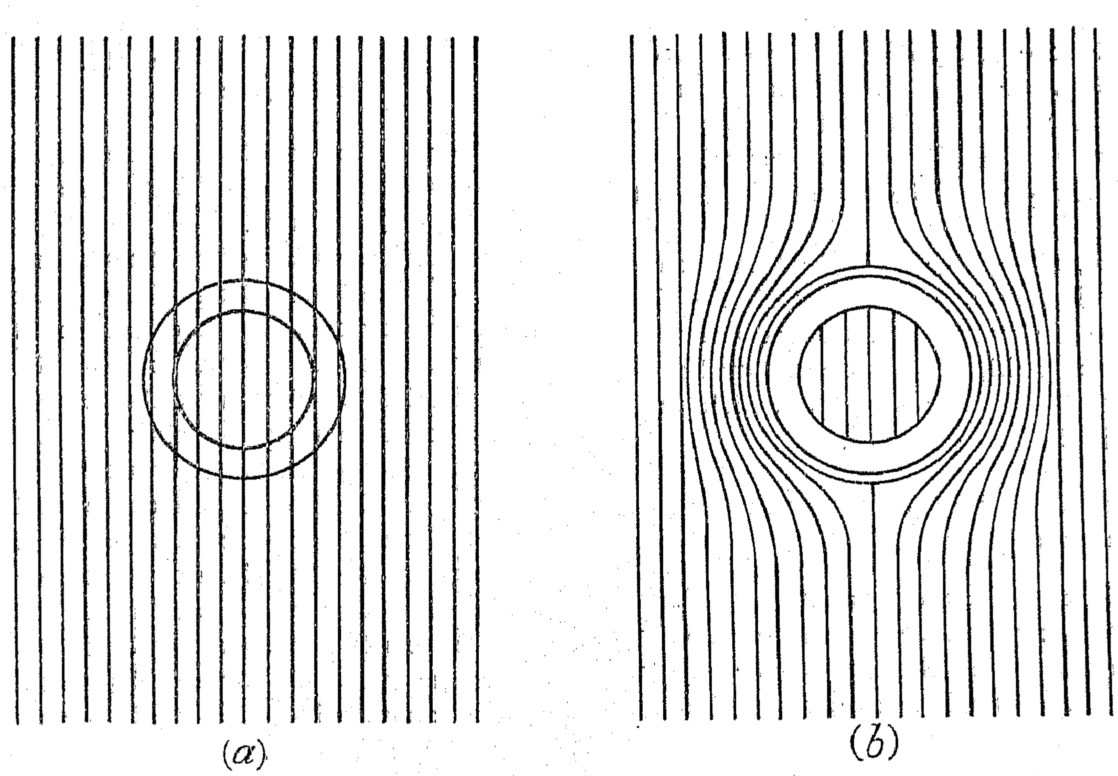

FIG. 15.—Tube of tin in a magnetic field.
(a) $T > 3{\cdot}7°$ K.
(b) $T < 3{\cdot}7°$ K.

emitted by mesothorium, and the lead sheet had a thickness sufficient to absorb, at ordinary room temperature, 50 per cent of the β-rays issuing from the mesothorium. In these experiments no measurable variation or discontinuity was detected in the absorption coefficient as the temperature of the lead was lowered through the critical value (7·2° K.). The high-velocity electrons from the mesothorium apparently encountered just as much resistance in their passage through the lead with the latter in the super-conducting state as when the lead possessed the normal conductivity exhibited at the higher temperatures. This investigation gave definite proof that although resistance in the super-conducting state is zero for currents carried by slow-moving electrons, it is not zero but maintains a normal value for currents carried by high-speed electrons.

Looking at the matter in another way, this result indicates, if the de Broglie wave equation $\lambda = h/(mv)$ applies, that lead at the lowest temperatures cannot exhibit super-conductivity when subjected to alternating electric fields with frequencies of the order of 10^{21} cycles per sec.

Photo-electric and Light-Absorption Experiments.

In a second series of experiments thin films of lead were deposited on plates of glass and of quartz, sometimes by cathode spluttering and at other times by vaporization of metallic lead. These films were subjected to a series of decreasing temperatures, commencing a few degrees above 7·2° K. and ending at the temperature of liquid helium (4·2° K.). The photo-electric effect and the absorption of visible light were in turn investigated with these films, and measurements were taken approximately by steps of a fraction of a degree as the temperatures of the films were lowered. In these experiments no measurable discontinuity was observed in the results of the measurements on the photo-electric effect, nor in the results of those on the coefficient of absorption of the light waves when the lead films traversed were passed through the transition temperature of 7·2° K. These results were therefore taken to indicate that super-conductivity with lead is a phenomenon that cannot be exhibited when electric fields alternating with a frequency approximately equal to or greater than 10^{14} per sec. are used.

It is clear, however, since super-conductivity can be brought into evidence by the use of unidirectional fields, i.e. with fields of zero frequency, that there must exist some critical alternating field, with a frequency between zero and 10^{14} per sec., by the use of which super-conductivity should just be detectable.

Experiments with Radio-Frequency Electric Fields.*

Through the development which has taken place in recent times, it is a comparatively simple matter to arrange combinations of oscillating valve systems capable of providing alternating electric fields with frequencies as high as 10^7 or even 10^8 cycles per sec. Some experiments were therefore made with radio-frequency fields of approximately 10^7 cycles per sec., corresponding to a wavelength of about 30 metres. The experiments and apparatus used, together with the theory applicable, have been fully described elsewhere and are therefore only briefly referred to here.

* See Bibliography, (35).

A resonant circuit was constructed consisting of a coil of the wire under investigation, which was wound on a former in series with a condenser mounted on the same former. The entire electrical circuit was made of the metal under investigation. The resonators used in the experiments were made of lead, of tin, and of tantalum. The plates of the condenser were kept at the proper distance apart by fibre washers on the central spindle. This resonator, in the experiments, was kept in the Dewar (unsilvered) flask in which the liquid helium or gaseous helium of a low temperature was produced. Temperatures were measured with helium-gas thermometers or were deduced from the vapour pressure of the liquid helium.

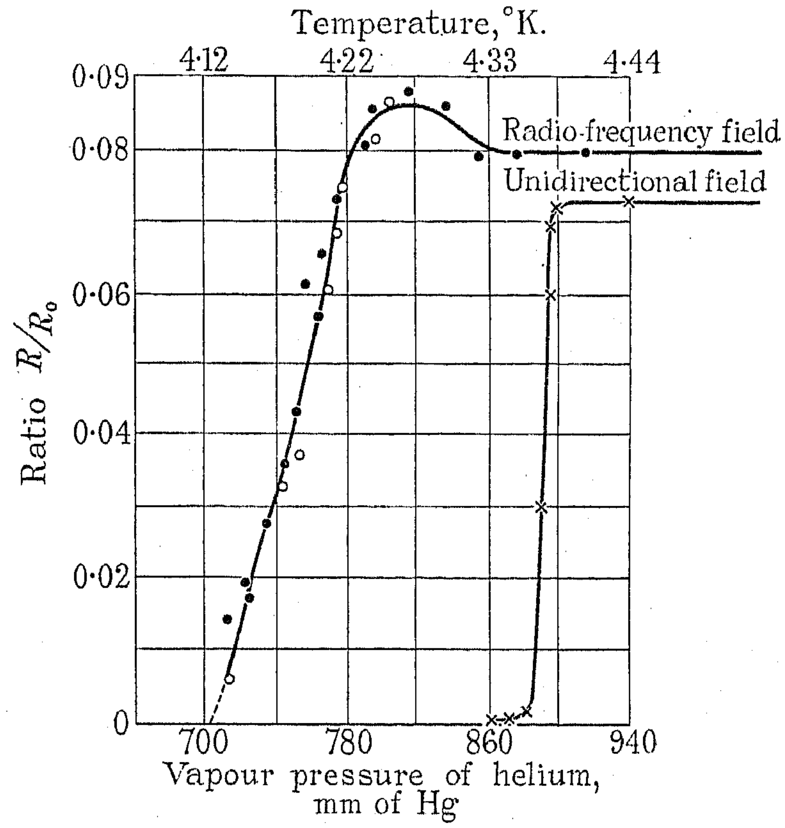

FIG. 16.

° Points obtained with a very weak coupling.

A reactance method was used and the plate and grid coils of the oscillating system were placed, properly screened, external to the vacuum flask containing the resonator circuit and immediately below it. The magnitudes of the currents induced in the resonance coil were measured by their reaction upon the oscillations in the generating circuit as indicated by the plate current of the latter. Measurements made in this way enabled one to deduce the value of the a.c. resistance in the resonance circuit when fields of different frequencies were used at various selected low temperatures.

The results obtained are typified by those for a solid tantalum wire illustrated by the curves in Fig. 16. These curves indicate that the transition point was lower where fields with a frequency of $11·4 \times 10^6$ cycles per sec. were used than it was with unidirectional fields. The curious hump* in the high-frequency curve was

* See Bibliography, (36).

originally ascribed to an experimental error. A closer study, however, has seemed to show that with alternating applied fields there is a phase variation in the current as one passes from the surface to the centre of a solid wire which may account for the effect. A difference of 180° or more between the phase of the current at the surface and that at the centre may exist. It may happen then that a decrease in the ohmic resistance of the central elements of a conductor produced by a lowering of the temperature will result in an increase in the total a.c. resistance of the conducting wire, through the current being confined to a thinner shell.

The initial experiments with alternating electric fields applied to solid conducting wires seemed to show that at frequencies higher than 10^9 cycles per sec. super-

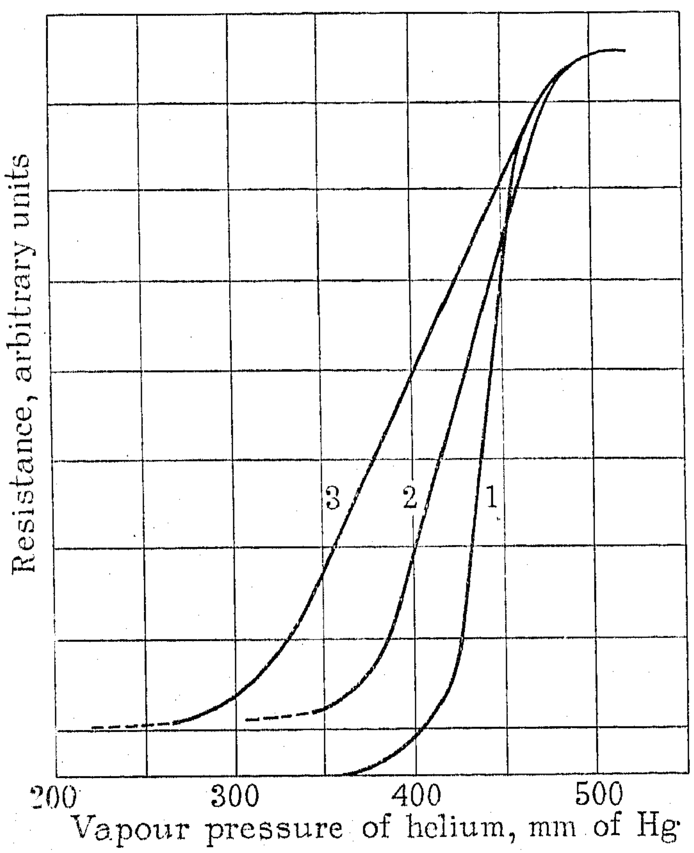

FIG. 17.—Curves for film of tin on constantan wire.

(250 mm pressure ≡ 3·22° K.; 500 mm ≡ 3·79° K.)
Curve 1. Direct current, 50 milliamps.
Curve 2. 10^7 cycles per sec., 25 milliamps.
Curve 3. 3×10^7 cycles per sec., varying current.

conductivity was not obtainable with a wire of any kind of metal. Later experiments, however, made with looser coupling between the oscillating and resonance circuits, have yielded results, particularly with thin films of metals used in place of solid wires, that prove this conclusion to be not valid generally. Fig. 17 contains curves that illustrate the results obtained with a thin (0·002 mm) film of tin "wiped" upon a constantan wire having a diameter of 0·016 cm. Curve 1 represents the d.c. resistance measurements with a current of 50 mA, Curve 2 gives the high-frequency resistance with an alternating current of 25 mA having a frequency of 10^7 cycles per sec., and Curve 3 shows the high-frequency resistances obtained with currents of varying value but always having a frequency of 3×10^7 cycles per sec.

Three striking characteristics of super-conductors are revealed by these curves: (*a*) The transition temperature is the same for both unidirectional and high-frequency fields when small current values are used. (*b*) The disappearance of the resistance, or the vanishing point, is at a lower temperature for high-frequency resistance than for d.c. resistance: in fact, the value of the apparent resistance with the high-frequency currents never becomes absolutely zero as the d.c. resistance does. (This is probably because the apparent resistance is partly ohmic and partly induced.) (*c*) There is no indication of a slight rise in resistance before the films become super-conducting to high-frequency currents, such as is invariably observed with solid wires of the same material.

It is interesting to note that with films there is no appreciable change in the transition temperature as between direct currents and alternating currents for frequencies up to 3×10^7 cycles per sec.

In view of the results obtained with films of lead in a study of the absorption of β-rays, the transmission of light, and the photo-electric effect, which showed no discontinuities at the transition temperature for direct currents, it would seem desirable to pursue the investigation further with currents having frequencies between 3×10^7 and 10^{14} cycles per sec.

THE EFFECT OF SUPERIMPOSING DIRECT CURRENT AND ALTERNATING CURRENTS.

Experiments have been carried out at Toronto with both solid wires and thin films of super-conducting metals—tin, for example—to determine (1) the effect of superimposing direct current on the high-frequency current while measuring the high-frequency resistance, and (2) the effect of superimposing high-frequency current on the direct current when measuring the d.c. resistance.

The results obtained with films of tin deposited on constantan wires illustrate the effects observed: (1) There is no appreciable effect on the transition point for high-frequency resistance due to the superposition of a direct current for small values of the latter. (2) The effect of superimposing high-frequency currents on direct currents while measuring d.c. resistance is to lower the transition or critical temperatures of the film investigated. The effect depends on the magnitude of the alternating current, and not at all on its frequency.

FILM THICKNESS AND TRANSITION TEMPERATURES.

Some experiments recently made by Burton* and his co-workers at Toronto on transition temperatures for films of tin of different thicknesses have yielded results of considerable importance. The films were made by electro-plating wires of different metals according to the method of Mathers and Bell,† and the transition temperatures were determined with each film for currents of 6 mA, 18 mA, and 200 mA.

A typical set of results is given in Table 4 and illustrated diagrammatically in Fig. 18. It will be seen that the transition point of a tin film recurred at a lower and lower temperature as the film was reduced below 10×10^{-5} cm. Above this thickness the transition temperature was practically constant for currents of small intensity. For thicknesses of 2×10^{-5} to 3×10^{-5} cm the films did not become super-conducting at all, even when temperatures as low as 2° K. were used.

* See Bibliography, (37). † *Ibid.*, (38).

A striking feature shown by the results in Table 4 is that the influence of increasing currents in lowering the transition temperature is very much more marked with thin films than with thick ones. This would indicate that it may be advisable to consider current density in a super-conductor rather than current strength as the more important factor in developing a theory for super-conductivity. In these experiments with tin deposited on wire cores Burton also examined the effect of coating the thin films of tin with an outer film of copper or nickel. The very striking result obtained was that a tin film which ordinarily became super-conducting near its normal transition point (say, for example, $3 \cdot 7°$ K.) lost its super-conducting property when covered with a film of copper or nickel. It was found that neither the thickness of this outer coating (from 7×10^{-5} cm to 10^{-3} cm), nor the material (nickel or copper), varied the depression of the transition temperature. Systematic investigation of films of various thicknesses showed that there was a limiting thickness of tin (about 40×10^{-5} cm) below which this loss of super-conductivity showed itself; but even for much thicker tin films the transition point was lowered when the outer coating was put on. The results are given in Table 5, and curves representing them are shown in Fig. 19. It will be seen that the coated tin film of

TABLE 4.

Transition Points for Films of Different Thicknesses.

Thickness of tin film	Material of wire core	Diameter of core	Transition point (in °K.) for currents of:— 6 mA	18 mA	200 mA
cm		cm			
200×10^{-5}	Constantan	0·056	—	—	3·78
90×10^{-5}	Constantan	0·056	3·78	3·76	3·74
37×10^{-5}	Constantan	0·056	3·77	3·76	3·73
10×10^{-5}	Constantan	0·056	3·71	3·66	3·61
9×10^{-5}	Phosphor bronze	0·040	—	3·64	3·54
$6 \cdot 8 \times 10^{-5}$	Constantan	0·056	*	3·60	3·49
5×10^{-5}	Constantan	0·056	—	2·54	—
4×10^{-5}	Chromel	0·040	—	3·25	3·00
4×10^{-5}	Manganin	0·045	—	3·12	2·92
2×10^{-5}–3×10^{-5}	Constantan	0·056	3·23	3·10	2·48
$2 \cdot 5 \times 10^{-5}$	Constantan	0·056	Non-super-conducting above 2° K.		
$1 \cdot 6 \times 10^{-5}$	Constantan	0·056	Non-super-conducting above 2° K.		
$0 \cdot 8 \times 10^{-5}$	Constantan	0·056	Non-super-conducting above 2° K.		

* 3·64° K. at 2 mA.

TABLE 5.

The Effect of Outer Coating on the Transition Point.

Thickness of tin film	Outer coating: Material	Thickness	Transition point (in °K.) for currents of:— 6 mA	18 mA	200 mA	500 mA
cm		cm				
200×10^{-5}	—	—	—	—	3·78	—
200×10^{-5}	Cu	80×10^{-5}	—	—	3·75	3·74
90×10^{-5}	—	—	3·78	3·76	3·74	3·70
90×10^{-5}	Ni	86×10^{-5}	3·71	3·69	3·65	3·58
90×10^{-5}	Cu	80×10^{-5}	3·71	3·69	3·65	3·58
50×10^{-5}	—	—	—	3·75	3·72	3·69
50×10^{-5}	Ni	241×10^{-5}	—	3·70	3·64	3·54
50×10^{-5}	Cu	7×10^{-5}	3·72	3·69	3·64	—
37×10^{-5}	Cu	37×10^{-5}	Non-super-conducting above 2° K.			
20×10^{-5}	Cu	10×10^{-5}	Non-super-conducting above 2° K.			
18×10^{-5}	Cu	40×10^{-5}	Non-super-conducting above 2° K.			
15×10^{-5}	Ni	30×10^{-5}	Non-super-conducting above 2° K.			
9×10^{-5}	Cu	100×10^{-5}	Non-super-conducting above 2° K.			

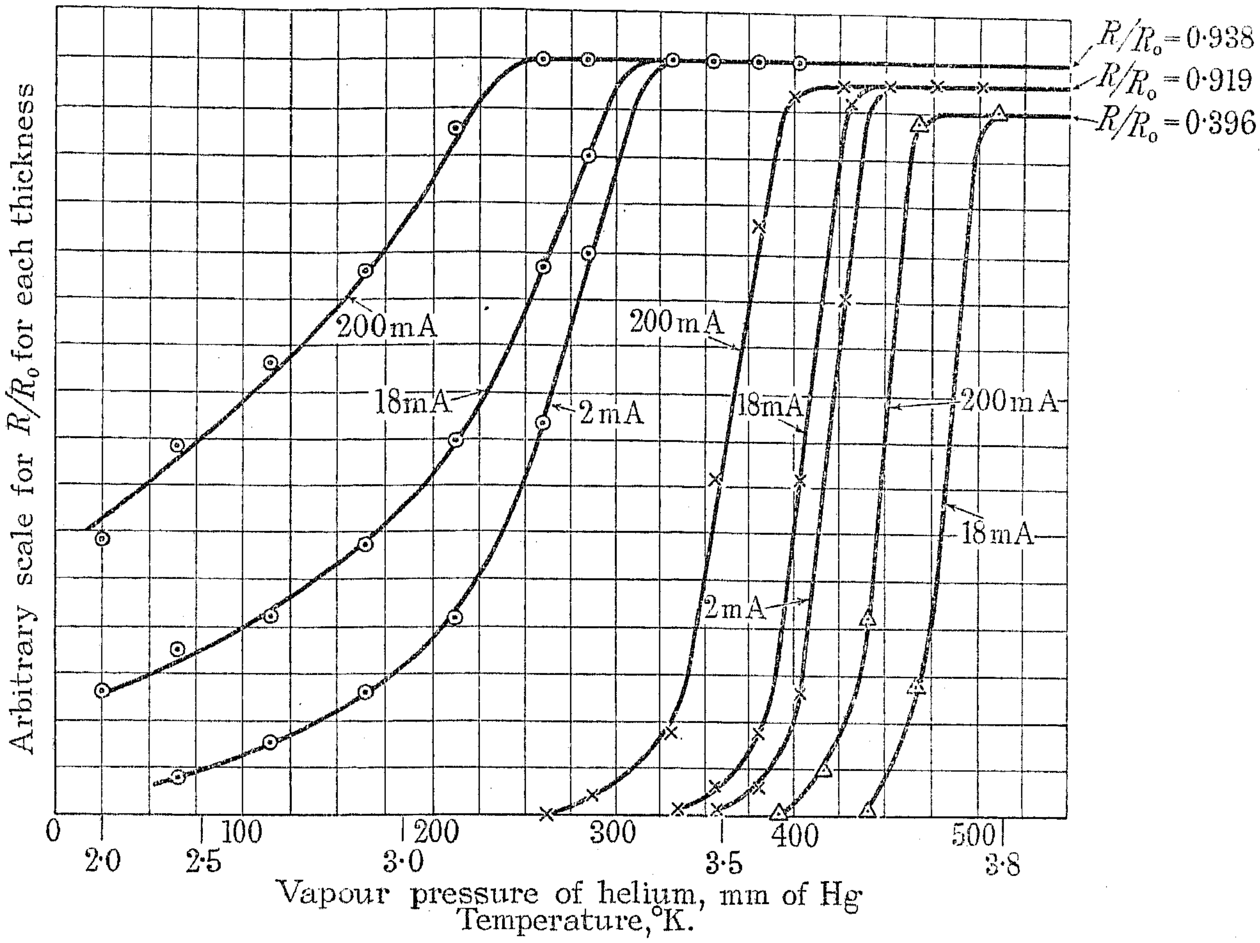

FIG. 18.

⊙ Thickness of tin film = 2 × 10^{-5} to 3 × 10^{-5} cm.
× Thickness of tin film = 6 × 10^{-5} to 8 × 10^{-5} cm.
△ Thickness of tin film = 10 × 10^{-5} cm.

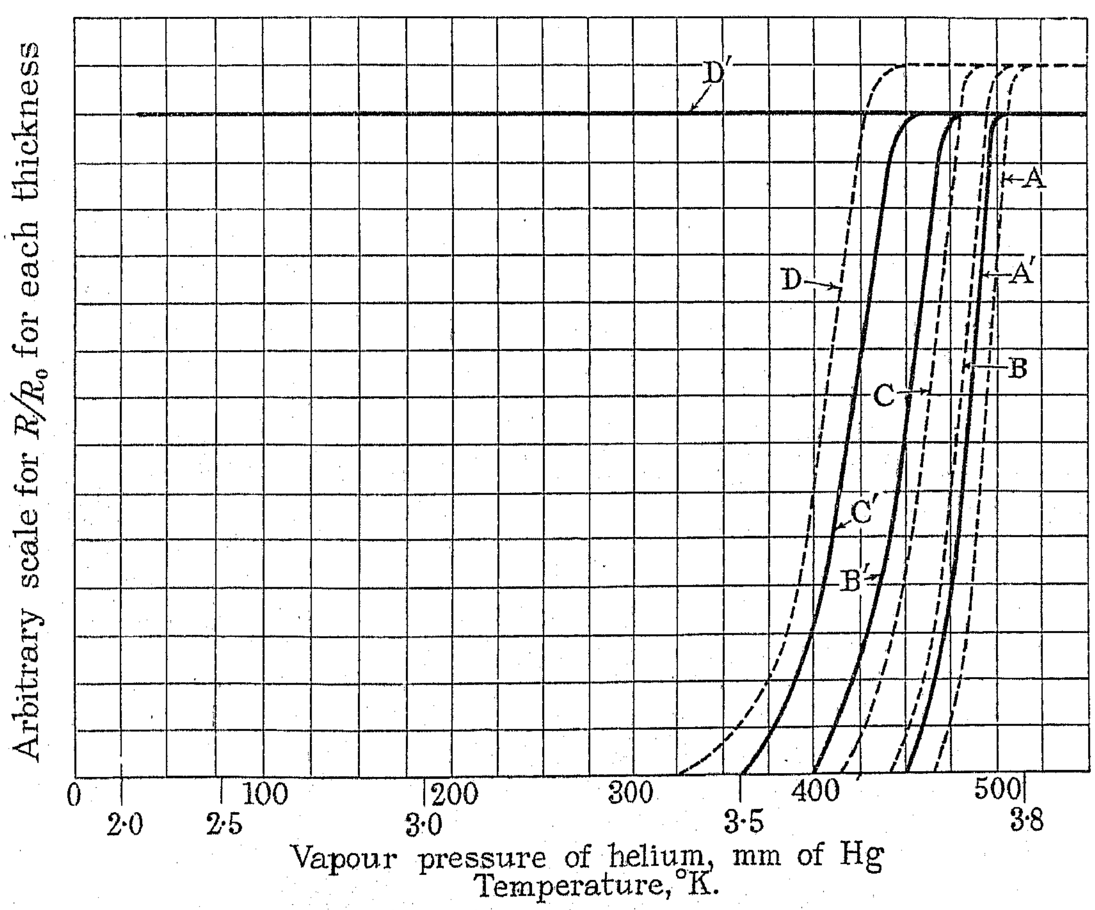

FIG. 19.—Curves for film of tin on constantan core, with and without coating of copper. Effect of (i) thickness of film, (ii) surface coating.

.... Uncoated tin films.
———— Coated with copper.

For curves A and A′, thickness of tin = 200 × 10^{-5} cm.
For curves B and B′, thickness of tin = 90 × 10^{-5} cm.
For curves C and C′, thickness of tin = 50 × 10^{-5} cm.
For curves D and D′, thickness of tin = 6·8 × 10^{-5} cm.

D′ not super-conducting above 2° K.
Thickness of copper coating > 10^{-4} cm.
Current, 18 milliamps.

thickness 50×10^{-5} cm became super-conducting at about 3° K., while that of thickness 37×10^{-5} cm was prevented from becoming so—certainly for a temperature as low as 2° K.

These experiments on thin films, and those made by Burton with the mercury-lard emulsion, are among the most interesting as yet carried out in the investigation of super-conduction in metals. It seems highly desirable to have those with films made at still lower temperatures than 2° K., possibly at the temperatures obtainable through adiabatic cooling brought about by the demagnetization of paramagnetic salts. It would be interesting also to repeat the experiments of Meissner and Ochsenfeld with deposited thin films of different thicknesses, both when uncoated and when coated with outer films of copper. A study, by the use of X-rays, of the crystal structure of these deposited films of tin—coated and uncoated—might possibly too yield results of value in connection with the elucidation of super-conductivity.

Theoretical Considerations.

Among those who have offered theoretical explanations of the phenomenon of super-conductivity is Brillouin,* who has considered the possibility of assuming the super-conducting state to correspond to a meta-stable current-carrying distribution of the conduction electrons over different energy levels in the ionic lattice of the metal, and of assuming that at higher temperatures the lattice vibrations destroy the meta-stability. One defect in Brillouin's theory is that it does not provide for the sharp transition to super-conductivity observed experimentally.

A theory put forward by R. de L. Kronig† seems better suited to explain the facts. On this theory a part of the conduction electrons are supposed to form below the transition point 1-dimensional chains which can move freely through the ionic lattice. The transition temperature can be considered to be the melting point of this electronic lattice.

Amplifying Kronig's theory, Frenkel‡ has recently pointed out that 1-dimensional lattices, or rather movable chains of bound electrons, will be stable and will suffice for the explanation of super-conductivity.

Such chains need not be movable in all directions. It will suffice to suppose them to be movable in one particular crystallographic direction corresponding to the smallest spacing between the atoms, the dielectric constant being infinite for this direction and preserving a finite value for all the others. It is customary to describe the super-conducting state of a metal by setting its specific conductivity equal to infinity. Frenkel directs attention to another possibility, namely, that the super-conducting state can be described much more adequately by setting equal to infinity the dielectric constant (κ) of the substance, its conductivity (σ) remaining finite or even becoming equal to zero. With Frenkel's modification of Kronig's theory a super-conductor could be described as a body with zero magnetic permeability ($\mu = 0$) and a dielectric constant given by $\kappa = \infty$, its electrical conductivity (σ) in the exact sense of the term being finite or even zero.

Frenkel makes a comparison of the mechanism of ordinary electric conduction (σ finite) and of ordinary polarization (κ finite). In the former case the electrons called "free" move independently, the conduction current being constituted by a drift motion due to the action of an external electric field and superimposed on the unperturbed random motion of the individual electrons. In the latter case the electrons called "bound" are displaced by the electric field simultaneously in the same direction, the polarization current being due to an orderly collective motion of all the electrons. Under normal conditions the displacement of the electrons with regard to the respective atoms remains small compared with the interatomic distances; this corresponds to a finite value of the dielectric constant. The assumption that the latter becomes infinite means that under the action of an infinitesimal field the electrons are displaced simultaneously over finite distances, each of them passing successively from one atom to the next, like a chain gliding over a toothed track.

According to Frenkel a collective motion of the "bound" electrons will constitute an electric current just as much as the individual motion of the free electrons but a polarization current rather than a conduction one. The electrostatic mutual action of the electrons moving collectively in a chain-like way will stabilize them against the perturbing action of the heat motion of the crystal lattice. This will result in the permanence of the polarization current after the disappearance of the electric field by which it was started. This permanence, which has been interpreted hitherto as corresponding to an infinite value of the specific conductivity, must be interpreted on the new view as corresponding to an infinite value of the dielectric constant.

Though the explanation of super-conductivity offered by Frenkel is essentially of a formal character, it should be mentioned that he has given strong reasons in support of the view that with a metal one should expect to realize a physical state characterized by an infinite dielectric constant. Grayson Smith of Toronto,* who has recently made a critical review of all available experimental data on the super-conducting state of metals, concludes that the only way of accounting for the results of the Meissner and Ochsenfeld experiments is to assume that there arises spontaneously, as the metal passes through the transition point, a system of local electric currents giving a sort of microstructure to the metal. Such a conception had already been suggested by Frenkel, but Grayson Smith has pointed out that the magnetic property of super-conductors allows an estimate to be made of the minimum breadth of these vortex systems. It appears that they must be greater than 10^{-5} cm in breadth. This, it will be noted, is in fair agreement with the actual thickness of thin films below which there is a marked interference with the onset of super-conductivity.

In concluding this lecture I should like to draw attention to the attempt now being made by Kapitza in the Royal Society–Mond Laboratory at Cambridge to liquefy helium without having recourse to the use of liquid hydrogen as an intermediary cooling agent. Kapitza proposes to use liquid air alone for external cooling and

* See Bibliography, (39). † *Ibid.*, (40). ‡ *Ibid.*, (41).

* Communications of the Kamerlingh Onnes Laboratory, Leiden.
† See Bibliography, (42).

to reduce the temperature of the gaseous helium below its inversion point by making the gas do mechanical work against a small engine of special design included in the helium gas cycle. From present indications it is highly probable that Kapitza's attempt will culminate in a brilliant success.

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MODERN PRACTICE IN GERMANY AND THE EUROPEAN CONTINENT WITH REGARD TO SUPERVISORY CONTROL SYSTEMS AS APPLIED TO LARGE INTERCONNECTED SUPPLY AREAS.

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(*Paper first received* 31*st October*, 1933, *and in final form* 20*th August*, 1934; *read before* The Institution 3*rd May*, 1934.)

Summary.

The paper first describes the development of the use of remote-control equipment on power systems, and then outlines the constitution and duties of the staff required for operating a large load-despatching plant.

The difficulties associated with the control of generation, particularly during peak-load periods, are next discussed, and the starting characteristics of various large turbo-generators installed at the stations of the Berlin municipal undertaking are given. Steam-accumulator sets, Diesel sets, and storage hydro-electric pumping plants, are relied upon in Continental practice to provide reserve power. In the operation of large systems, frequency meters are now being supplemented by remote-metering devices for use in balancing output and demand.

Where a large number of generators feed into the network, both the individual outputs and the summated values for the various groups are transmitted to the load dispatcher by the remote-indicating equipment. This is usually operated on the impulse-frequency system, either over pilot wires or by means of carrier-current circuits.

Network compensation is obtained by adjusting the earth-leakage coils so that their inductance balances the total capacitance of the interconnected system. The necessary adjustments to the coils are made by local attendants under the direction of the load dispatcher.

Carrier-current telephony is commonly used for communication between the load dispatcher's office and the various control points, on account of its lower cost and greater ease of fault location as compared with other systems.

Supplies to medium-sized towns, densely-populated rural areas, and electric railways, are given from secondary networks, each of which is controlled from a district load-dispatcher's office situated at a power station or substation. The results of remote control on such networks have been very satisfactory.

(1) Introduction.

In studying any engineering development it is interesting to compare the historical origin of the subject with its technical status to-day. It is often found that the development at first diverges from the originally conceived idea, but returns to it again in essence and conception when reaching completion. Such a departure from first practice may be observed in regard to the subject of load-dispatching, a short survey of the stages of development of which will now be given.

The birthplace of the load-dispatching plant was really the main switchboard of the oldest and largest power station of a town. Here were concentrated all the generators and the ends of all the main feeders leaving the station. The control of the whole service was centred in the chief engineer, who was responsible not only for the perfect condition of his machines and entire distribution system but also for the choice and operation of the generators so as to obtain the greatest economy. His duties therefore extended not only to technical but also to economic problems. Even after the installation of one or more smaller power stations, the largest power station still remained the central point of the whole system, either because the power from the secondary station or stations was fed to the busbars of the central station, or because, if that was not possible, a simple telephone was used for directing the operation of the auxiliary stations from the central station. The breakdown of such a secondary station did not in all cases affect the supply of current to the consumer.

Reviewing the development of load dispatching, we find on the one hand that for a time it was subject to bureaucratic control. In the load-dispatching office the daily reports of all the power stations of the system were collected, and on the basis of these reports the orders for the next day were issued. At the same time the most efficient method of running the whole system was calculated. In some cases simple slowly-working remote-metering devices were used for transmitting the principal operating data, whilst the only means of communication was the telephone. The present-day load-dispatching plant, on the other hand, has a much greater resemblance to the original main switchboard. The functions of the engineer in charge are of a much higher order, more akin to the duties of the engineer of former times. He supervises the system, but delegates the work of manipulating apparatus and machines to local operators. His scientific training and experience qualify him to give advice in all matters regarding improvement and extension of the service.

The foregoing remarks indicate the nature of the methods and equipment required in connection with load dispatching.

(2) General.

The work to be done is of three different kinds: costing, which is dealt with by the statistical office; the supervisory and emergency service, which is in the hands of the load-dispatching engineer; and work connected with the erection of new buildings or the extension of existing ones.

The fact that in modern systems there is no main switchboard and that facilities for rapid working and absolutely reliable communication are provided between

power stations, substations, and the load dispatcher, makes it unnecessary for the load dispatcher's office to be situated at any particular power station. The costs of cables or lines connecting the load dispatcher's office with all important points on the system may exercise a certain influence, but apart from this it is possible to choose the most favourable position. For instance, the whole plant may, if desired, be installed in the office building of the supply undertaking.

The staff required for a large load-dispatching plant is determined by the necessity of keeping up an uninterrupted service throughout the 24 hours. According to Continental experience the following staff is required: 1 chief engineer; 2 assistant engineers; 1 superintendent engineer; 2 shift engineers, each with 1 attendant and 1 skilled fitter; and 2 office assistants. Some information regarding the duties of the personnel in the load dispatcher's office will now be given.

The duties of the load dispatcher can be summarized as follows:—

(i) Distribution of non-reactive load among the several power stations and the purchasers of bulk supply; control of frequency, to ensure correct indication of synchronous clocks. For this purpose the reserve generators and boilers at all the stations must, of course, be at the disposal of the load dispatcher. These reserves are subdivided into two, namely the instantaneously-available reserves ready for the generation of power at any moment (running generators already synchronized, batteries of boilers, etc.), and the reserves represented by machines and boilers ready for starting up.

(ii) Distribution of reactive load between the power stations, purchasers of bulk supply, and reactive generators; control of voltage.

(iii) The control of the circuit breakers at the power stations, transformer stations, and switching stations. Control of the whole system often means the giving of special instructions in cases of emergency as well as during normal conditions if repairs or cleaning are necessary.

(iv) Control of network compensation and insertion of earth-leakage coils.

(v) Orders to the convertor stations for the charging and discharging of lighting batteries to deal with peak loads and to meet emergency conditions arising from failure or other trouble in power stations.

(vi) Taking the measures necessary for the running in parallel of all generators and for the fulfilling of contracts made with other undertakings who partly supply and partly consume power.

(vii) Control of the master clock according to the wireless time signals, and adjustment of all secondary clocks in the power stations.

(viii) Collection of all reports received from the supply undertaking's own power stations and from the undertakings operating in parallel, concerning disturbances, so far as the disturbances are noticeable in the system.

(ix) Issuing of daily, monthly, and yearly reports on the load conditions and amount of power generated in the power stations, on the power purchased or supplied in bulk, and on that supplied direct to consumers. These reports are the bases on which the statistical office carries out its researches.

(3) Power Generation and its Control.

The knowledge of the characteristic difficulties associated with load dispatching determines the choice of the necessary auxiliary equipment and the conditions to be fulfilled by it. It is not difficult to prepare within

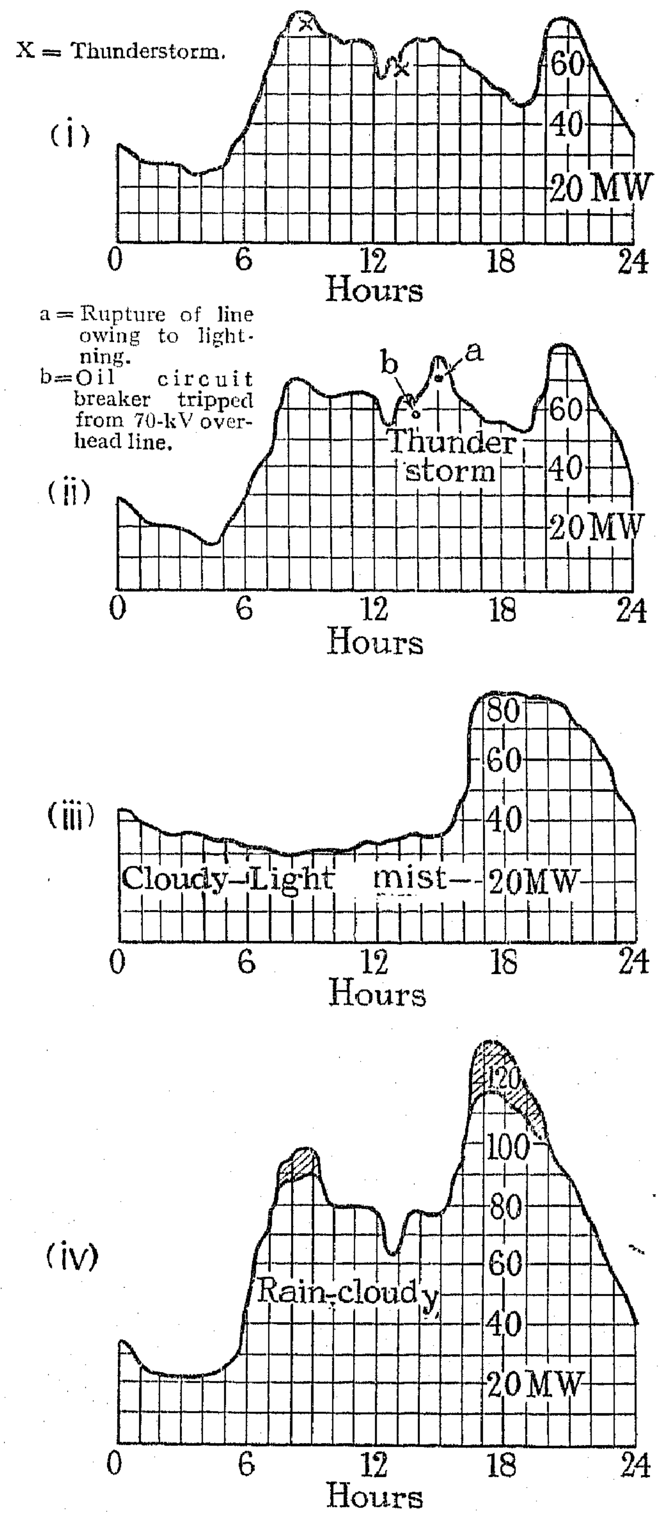


Fig. 1.—Load curves.

(i) Wednesday, 3rd August, 1932.
(ii) Monday, 6th June, 1932.
(iii) Sunday, 28th November, 1932.
(iv) Monday, 29th November, 1932.

10 per cent the normal daily programme in connection with the loads required during the various hours of the day. All that is required are the load records of the previous two or three days and, in addition, complete information as to the weather conditions and extraordinary events such as holidays. For this purpose no special technical equipment is required. The work can be done by the statistical office on the basis of diagrams received. For the proper operation of the system,

schedules must be worked out concerning the number of power stations drawn upon if uninterrupted supply and distribution of power during peak loads are to be maintained. Figs. 1 and 2 show such records of the daily load at various seasons.

To give an idea of the difficulty of the control engineer's work, attention is drawn to the steepness and the irregularity with which the power demand increases during peak hours, which vary with the time of the year and the weather. In a large town with an installed capacity of 500 000 kW the demand increases during winter peaks at an average rate of 10 000 kW per minute, i.e. 200 000 kW within 20 minutes. This means that in this short time the machines of one or two complete power stations must be put into operation. To enable him to handle such sudden loads, the load dispatcher must be assisted by a reliable and rapid meteorological service which, by means of a good system of communication, is in constant touch with weather bureaus, especially those of air-ports. Supply undertakings often possess their own weather stations. Apparatus has been constructed which automatically records the illumination from the northern sky. The illumination curves obtained with this apparatus are used for determining the rate at which the power demand is likely to increase. All the power stations, as a matter of course, immediately report any unexpected change in the weather, as only by this means is it possible to meet the demand for current in the event of a thunderstorm or fog (see Fig. 3).

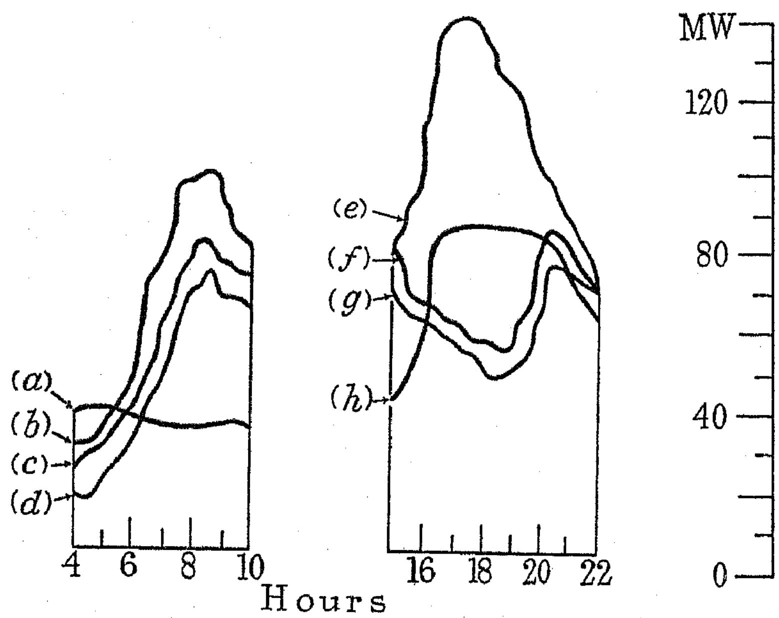


FIG. 2.—Load curves.

(a) Monday, 28th November, 1932.
(b) Wednesday, 3rd August, 1932.
(c) Monday, 6th June, 1932.
(d) Sunday, 20th November, 1932.
(e) Monday, 28th November, 1932.
(f) Sunday, 20th November, 1932.
(g) Monday, 6th June, 1932.
(h) Wednesday, 3rd August, 1932.

If the highest economy is to be obtained, the number of machines to be started and the time for doing so must be well considered. The cost and time involved in the starting of steam turbines may be illustrated by some figures obtained from experience gained on the system of the Berlin municipal electricity undertaking.* The period of preparation, from the moment the order for starting is given until the opening of the stop valve, is from 8 to 35 minutes. The time from the opening of the valve until full speed is attained is from 15 to 90 minutes, according to the construction and size of the turbines. The starting time further depends upon how long the machines have been shut down and on the extent to which they have cooled when out of service. On the Berlin undertaking's system the turbines are first heated by running them at a speed of 5 to 12 per cent of normal, and are then brought up to full speed during the second half or last third of the starting-up period. The time for synchronizing and switching on to the system is very short in comparison with the starting-up period. The time which must be allowed to elapse before the unit is available for service at full load depends generally upon the generator, as a certain period must always be allowed for the expansion, due to heat, of the iron and the windings of the rotor and stator. For this reason all the generators with the exception of the 80 000-kW machines are excited, during the time when the steam plant is being started, by means of their own exciters, in order to prevent damage to the insulation. The generators may only gradually be brought up to full load. For sizes up to 20 000 kVA 30 minutes is required, and for larger sizes 60 minutes.

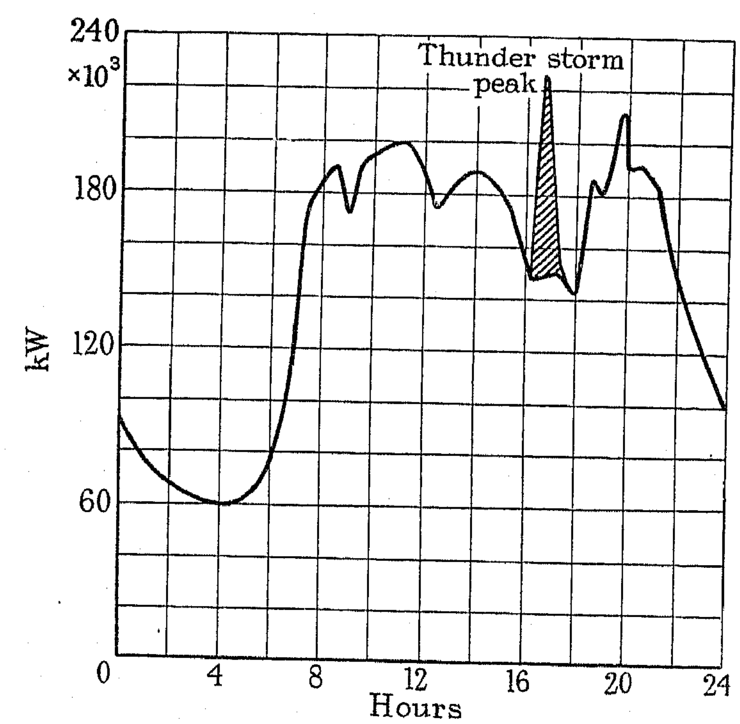


FIG. 3.—Load curve of the Bewag system for 19th April, 1929.

The loading of reactive machines takes place in the same manner. A 20 000-kVA reactive generator is run up to full speed in 1 to 4 minutes by means of a starting motor, whereupon it is connected to the system and gradually loaded. The large 80 000-kW sets require 35 minutes for preparation, 90 minutes for starting and speeding up, 10 minutes for synchronizing, and 155 minutes for loading. Five men are necessary for this work. These units are of the 2-shaft type, and must therefore be excited by auxiliary current. The time which must elapse before the machines may be fully loaded is not determined by the generators but by the high-pressure section of the turbines, owing to the time-lag between the expansion of the runners and of the casings. For the first hour the set is loaded up to only 15 per cent, and then the load is raised in steps of

* F. GROPP: "Starting-up and Putting into operation of Steam Turbines," *Elektrotechnik und Maschinenbau*, 1933, No. 18, p. 268.

10 000 kW. By reason of the very long period of $4\frac{3}{4}$ hours required from start to full load, these sets are only used as base-load machines.

The 34 000-kW sets are fitted with a rotor-turning equipment. If one of these sets is required within 24 hours after shutting down, the preparation takes 11 minutes, speeding-up 25 minutes, and loading 30 minutes. For this 4 men are necessary. If a set is to be put into service when completely cold, the rotor-turning device is first put into action for 1 hour, or, if that is not possible, the set may be started in the usual way. In this case, however, the loading time will have batteries, Diesel engines, and steam-storage or water-storage plants. Nearly all the peak loads and emergency reserves are under the direct control of the load dispatcher by means of separate remote control, remote indicating, or remote metering devices.

Storage batteries and Diesel sets are ready for operation at full load within a few seconds. A Ruth accumulator set such as is installed in Berlin requires 4 men for its operation, and takes 10 minutes for preparation, 33 minutes for speeding up, and 30 minutes for loading. If such machines are already running as reactive generators, they can in urgent cases be fully loaded within 20 seconds.

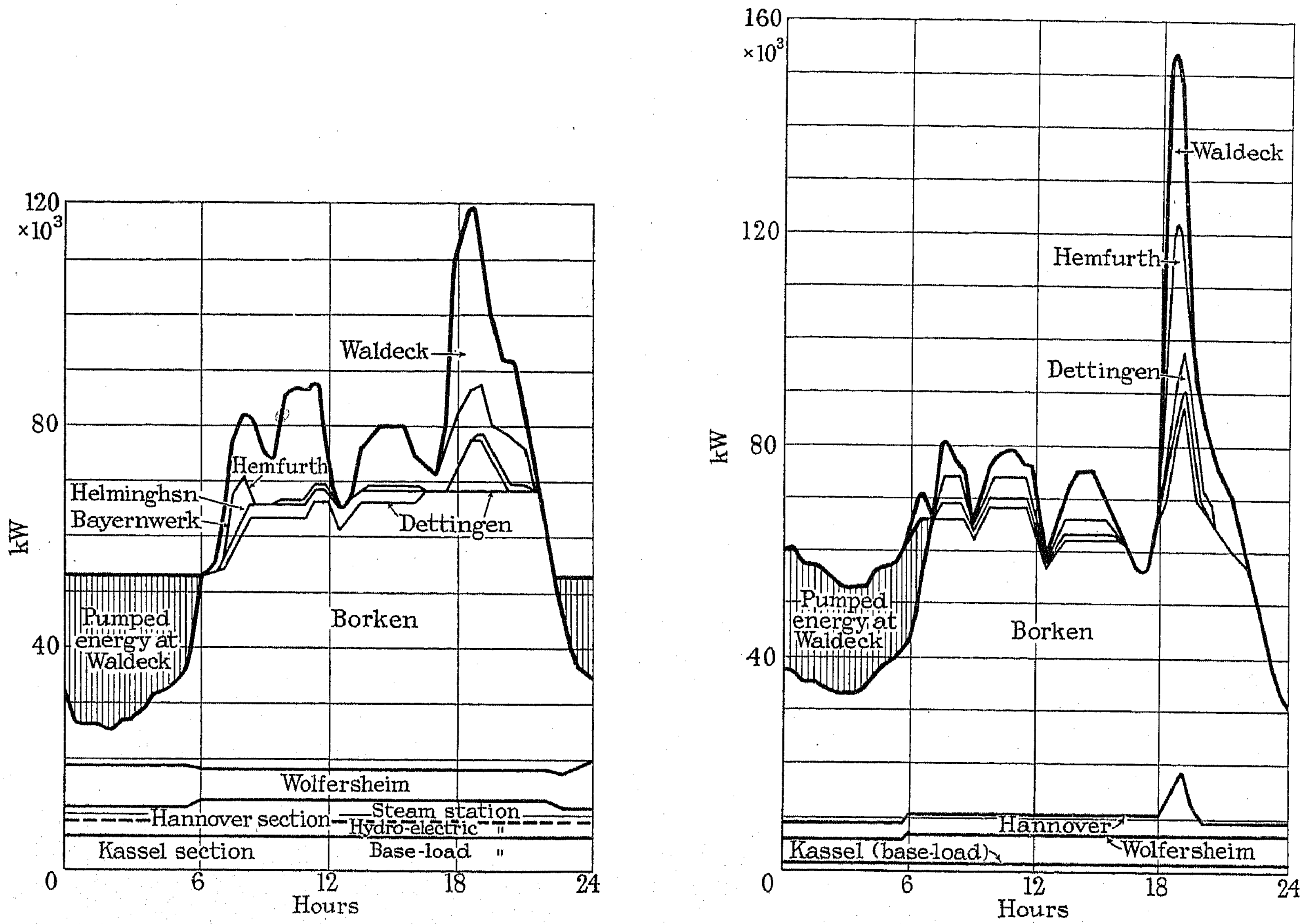


FIG. 4.—Load curves of Waldeck storage pumping station.

to be extended to 105 minutes. In emergencies, the loading time may be shortened to only 10 minutes.

The foregoing shows that the time required for starting large machines is very considerable, and supply undertakings are much interested in suitable means for shortening the starting period. In recent years the Berlin undertaking has had, on an average, 40 units in operation, and the total numbers of starts made were 4 140 in 1929, 3 480 in 1930, and 2 785 in 1931.

From this it will be seen that the starting of a machine is economic only if the machine can be kept in operation for a comparatively long period. The load dispatcher must therefore cover short peaks by means of what may be called instantaneous reserves, i.e. reserves ready to generate current at any time; for example, storage As the storage capacity of the steam accumulators is limited, the load dispatcher watches the steam pressure by means of a remote indicator.

In general, water power is very suitable as reserve power. The costs of production are very low when the available water power is used to carry base load. Only if surplus water is available may water power be used to carry peak loads. Since, however, water power possesses many advantages with regard to the very short time required for starting and loading, Continental practice is to employ storage hydro-electric pumping plants. Such plants are generally provided with automatic devices, and can be started and loaded by one man within $1\frac{1}{2}$ minutes. It is very useful to erect storage pumping stations near the centre of consumption,

i.e. in those districts where peak loads as a rule originate. Thus the advantage of this method is that greater economy is obtained.

In Germany there are already 11 pumping sets of this kind, each generating on an average 30 000 kVA. Some of the most modern plants are represented by the Herdecke, Schluchsee, Waldeck, and Niederwartha stations. Apart from being a stand-by, these plants have to balance the whole production. During periods of low consumption, water is pumped back into the reservoirs, thus enabling the machines to work under a uniform load, as shown in Fig. 4.

All the problems referred to above may be solved by relatively simple means, but, nevertheless, remote supervisory control has proved a very useful additional means for the purpose of facilitating the rapid co-ordination of the individual loads with regard to the requirements of the system as a whole. These simple means, however, are only adequate if reliable frequency meters are available. For a long time the frequency meter has been the best instrument for determining the conditions obtaining throughout the entire system. By means of its indications it can be ascertained whether at any moment there is a surplus or a want of power. The frequency meter has therefore served a very useful source of information.

In this respect, however, experience has shown that in the operation of large systems two difficulties arise. First, it was discovered that the greater the output of the generators working together on the system the greater must be the sensitiveness of the frequency meters. This statement may at first sight appear absurd, but the following example will make it clear. The total installed capacity of a system is composed of the capacities of a large number of units. The frequency meter can be regarded as the tongue of a balance, one scale of which is loaded with the total machine capacity and the other with the total demand. The greater the number of machines working on the system, the smaller will be the difference in frequency if, for instance, the equilibrium of the scales is disturbed by an excess demand of, say, 20 000 kW. This figure compared with a total capacity of, say, 500 000 kW, is very small, and the running machines will react only to a small extent on the frequency. On the other hand, 20 000 kW represents the full load of a comparatively large generator. For this reason frequency meters would have to be extremely sensitive if used in connection with large systems to determine whether a large set is to be started up. Secondly, it was found that a desired distribution of load in a system can only be maintained if the frequency is kept as constant as possible, since the speed governors of the various turbines possess different characteristics and therefore a fluctuation in the frequency will produce a different distribution of the load between the machines. If, therefore, in a large system, constant frequency is not maintained, no order can be kept in the distribution of the load and it becomes impossible to judge the conditions in the system. Thus on large systems the frequency meter cannot provide the necessary control.

Each of the power stations connected to a system should economically satisfy the demand for power in its own district and deliver its surplus power to the system; or, if that is not possible, power must be taken from the system to meet requirements. Formerly an increase or decrease in the demand could be ascertained by means of the frequency, and power supplied accordingly, but the frequency meter is now no longer suited to this purpose. In addition to frequency meters, remote metering devices must now be employed to transmit to the load dispatcher's room the indications of the loads prevailing at the points where the main system is connected to the local networks.

(4) Remote-Indicating Devices and Their Application.

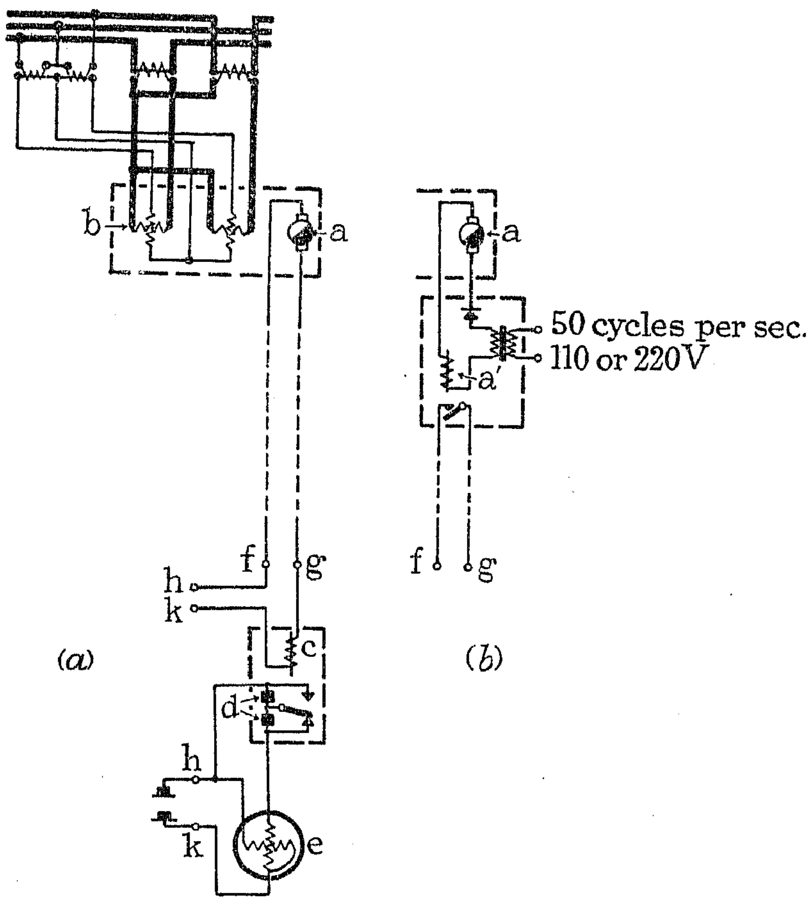
(a) Remote Metering of kW.

From the foregoing, the necessity of remote-indicating devices in load-dispatcher installations is evident. Not only are they necessary for the correct handling of the sources of power of each local system and in accordance with the contracts entered into with other undertakings, but they are also an indispensable auxiliary for the harmonious operation of large interconnected systems. As it is of the greatest importance for the load dispatcher to be able to judge beforehand how and to what degree the load will vary during the next few minutes, recording remote-metering instruments are indispensable.

Consider a system on which there are 100 generators. There would be no reason for transmitting the indications of the 100 generators singly to the load dispatcher, since it would not be possible for him to observe continuously all the data and add them up in groups. It is preferable to use systems which transmit values not only singly but also already summated. The apparatus at the load dispatcher's office must be so designed that these single or integrated values are continuously and automatically added up either in groups or to a grand total. Experience has shown that even this simplification of the representation of the total power consumed in the case of large systems is not sufficient to enable the load dispatcher to obtain a reliable survey and to be free in his dispositions. Two further methods for the rationalization of the distribution of the load have therefore been evolved.

The first method takes, in a sense, the place of the formerly-used frequency meter. The aggregate readings obtained are retransmitted to the individual plants of the system, so that at each plant its own total is known as well as the total of the whole system. Each plant takes over a certain percentage of the load on the whole system, according to a programme worked out from an economic point of view and issued weekly or daily. The Berlin undertaking, for instance, has introduced this method and found it to give very satisfactory results. The equipment associated with this method will be referred to later. The method affords a simple solution of the problem of maintaining a constant frequency, since all the generators take part in supplying the necessary power and therefore the frequency-stabilizing machines only require to deal with relatively small variations. It was found, however, that on systems exceeding a certain capacity, even the capacity of a large generator was not sufficient to keep the frequency constant if all the other generators were operating

at a fixed load. Moreover, the efficiency of a frequency machine of this kind is low, because the machine must be



(a) Line resistance less than 600 ohms; without transmitting relay.
(b) Line resistance more than 600 ohms.

FIG. 5.—Remote metering by impulse frequency method.
(See key below Fig. 6.)

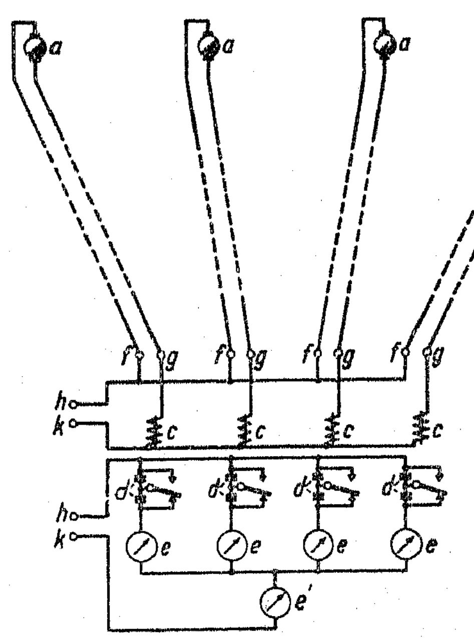


FIG. 6.—Impulse-frequency remote-metering: summation of individual remote-metered values.

a = Interrupter, producing impulses.
a' = Transmitting relay.
b = Measuring system.
c = Receiving relay.
d = Condensers.
e = Receiving instrument.
e' = Summating instrument.
f, g = Terminals of the remote line.
h, k = Terminals for the auxiliary battery.

continually regulated between no load and full load, and therefore the load on the boiler is also irregular, so that the boiler efficiency is poor.

In the second method automatic load regulators in conjunction with remote-metering devices are used. By this means it is possible automatically to maintain constant output of certain preselected power stations or single generators. This output may be changed from time to time by order of the load dispatcher. In general he can rely upon fixed conditions, on which he then bases his other dispositions.

As remote-metering devices are used in connection with automatic load regulators, it may be useful to devote a few remarks to the characteristics required of apparatus which in practice has rendered good service to the load dispatcher. In view of the rapidity with which the load increases and decreases, the necessity for observing the increase and decrease, and the fact that the transmitted values must represent the sum of a large number of individual values, it is clear that only

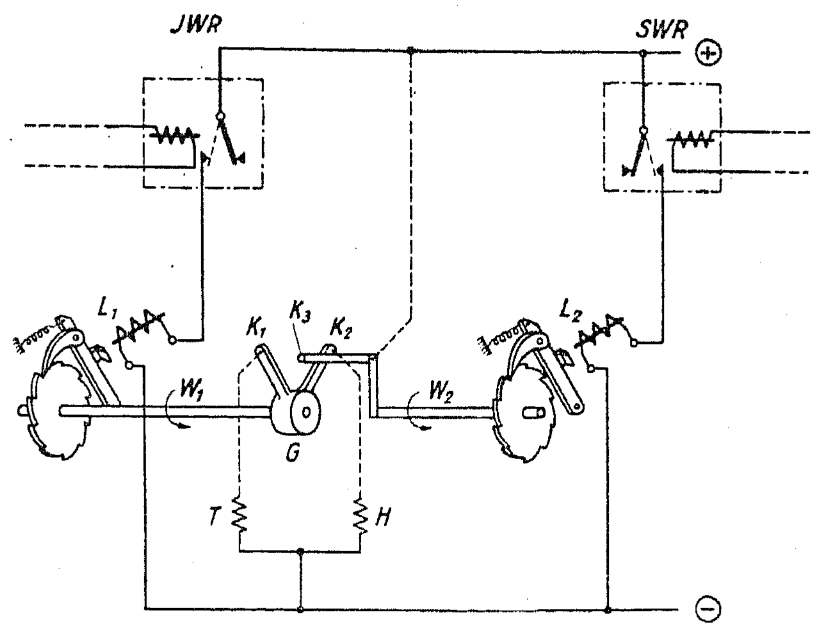


FIG. 7.—Energy and frequency controller (fundamental lay-out).

JWR = Receiving relay for metered values.
SWR = Receiving relay for values to be maintained.
L_1, L_2 = Stepping gears for rotating W_1 and W_2.
G = Fork.
K_1 = Contact for lowering the load.
K_2 = Contact for raising the load.
K_3 = Middle contact.
T = Relay for lowering the load.
H = Relay for raising the load.

rapidly-indicating and rapidly-transmitting instruments can meet the requirements of load dispatching. It is not permissible for any time to be lost in the summation, and reliability and accuracy are also of first importance. It might be thought that a lag of a few seconds in the transmission of metered values would not make any difference; but experience has shown that the greatest possible degree of synchronism must exist between the metering and the reception of the summed values at the dispatcher's office. All small irregularities and fluctuations must be recognizable, as they may be caused not only by consumers but also by insufficient attention at one of the plants, or by other factors such as irregular working of turbine governors. In all cases the load dispatcher must be able to eliminate the causes of such irregularities at once. Efficient remote-indicating systems have frequently been the means of discovering faults which had remained unknown to the local engineers.

Of all the remote-indicating systems used on the Continent, the impulse-frequency system is the most widely preferred; not only on account of rapidity of transmission and indication (see Fig. 5), simplicity of summation (Fig. 6), and the possibility of its being used in connection with automatic regulators (Fig. 7), but especially owing to the fact that it is completely independent of the kind of transmission channel used. Direct connection by means of pilot wires and connection through carrier-current circuits are equally possible, and it is possible to transmit several values simultaneously or to use the same channel for the simultaneous transmission of telephone conversation and metered values. Protection against the influence of high-voltage lines may be easily achieved. On the Continent, supply undertakings prefer to use their own private transmission lines rather than to hire Post Office lines.

(*b*) *Remote Metering of kWh.*

Contrary to expectations, the remote metering of kWh over long distances has not yet been applied to any great extent, even on the lines connecting the systems of two companies. Although the values of the power passing over such lines are summed, the totals are transmitted only by telephone. The author knows of only one instance in which the time regulators of quarter-hour maximum-demand meters are synchronized by carrier-current impulses. The device used for this purpose is protected against faulty transmission of the synchronizing impulses, so that correct timing is obtained.

(5) Control of Network Compensation and Supervision of the Condition of the System as Determined by the Switch Positions.

Centralized network compensation is of as great importance as centralized supervision of load distribution, because the total inductance of the earth-leakage coils must be made to balance the total capacitance of the interconnected system. This problem leads us to the closely related one of the supervision of the condition of the system at any time. It is a maxim in Continental practice that the load dispatcher must not operate switches or similar devices himself except in extreme emergencies, when he must be in a position to put " instantaneous " reserves into operation directly or to split up the network according to pre-arranged plans. The load dispatcher as a rule only gives orders by telephone or tele-typewriters, such orders being carried out by district dispatchers (referred to later in the paper) or by local attendants. In general, all operations affecting the main system are carried out at night or on Sundays. Normally the load dispatcher's work is assisted by an automatic remote-signalling device, sometimes operated in connection with illuminated circuit diagrams.

As has already been mentioned, the load dispatcher has to determine the proper adjustment of earth-leakage coils. The methods of doing this are as follows: (i) The required compensation is calculated by a simple mechanical apparatus which adds up the capacitance of the single lengths of lines or cables and shows the amount of compensation. Very primitive balances are generally used for this purpose, and therefore the method is not very accurate. (ii) The required compensation is measured directly by a compensator. At intervals of, say, 1 hour, a current of higher than normal frequency is injected into the system whereby its capacitance can be directly measured. The adjustment of the coils is carried out by local attendants according to given orders. In general, it is endeavoured to adjust the several coils distributed over the whole area in such a way that each section would remain compensated should it become necessary to split up the system. Recently an automatic remote-adjusting device for earth-leakage coils, operated by impulses transmitted by carrier current, has been installed as an experiment. It appears that the results obtained so far have not come up to expectations. Nevertheless, it is useful to be able to receive an automatic remote indication of the position of the tapping switches, even if remote operation proves definitely impracticable.

The distribution of the reactive load and the regulation of the voltage is carried out according to fixed time tables prepared by the load dispatcher. The regulation of the voltage depends chiefly upon local conditions and is performed by local devices, e.g. tap-changing arrangements on transformers. The responsibility for this part of the operation of large systems therefore rests with the local engineers.

(6) Other Means of Intercommunication.

In addition to the above-mentioned means of communication, the telephone plays an important part. A description of the methods of connection and the equipment will be found in the Appendix. Generally the arrangement is such that the load dispatcher is always given preference in speaking.

Carrier-current communication is very popular on account of its relatively lower cost where great distances are to be bridged, its reliability, and the greater ease with which, compared with wire systems, fault can be located. Duplicate-channel communication is generally used, to avoid the limitation in speaking imposed by a single-channel system. Switching stations are shunted by high-frequency condensers, and those parts of the high-voltage system not used for communication are blocked by high-frequency coils. Thus the small capacity (a few watts) of the high-frequency generators is sufficient to maintain a reliable service. Failures due to hoar frost are very infrequent, on account of the progress made in recent years in carrier-current communication.

It is estimated that in Germany, Belgium, France, and Italy, about 600 stations are in service. For remote-metering and remote control and network protection, carrier-current transmission systems are being more and more applied. It therefore becomes necessary to apply methods involving modulation, and to make use of the possibility of bringing the carrier waves closer together.

(7) District Load-Dispatchers.

Strictly speaking, there are on the Continent no district or secondary load-dispatcher's offices, but

several existing plants could very well be so called. By means of such district load-dispatchers the supplies of medium-sized towns, densely-populated rural areas, and electric railways, are controlled.

With regard to remote metering, conditions are here very similar to those which have already been mentioned in connection with the "chief" load dispatcher. Remote control from a central point is, however, necessary to a much greater extent in connection with district supplies, not only on account of the large number of stations which, owing to their small size, are without attendance or have only temporary attendance, but also for the reason that reliable operation is only possible in accordance with instructions received from points from which the whole system can be surveyed.

Such secondary networks are much more closely interconnected than primary systems, and the stations which feed them are more diverse in character. There are transformer stations, rectifier stations, rotary-convertor stations, phase-shifting stations, small hydro-electric power stations, and consumers who, during certain periods, also supply current. On such systems it is therefore of still greater importance to provide adequate technical means to obtain at one central point of supervision an exact and detailed representation of the operational condition of the entire system, as well as to carry out direct from one spot all necessary measures.

For this reason such district dispatcher's offices are fitted not only with remote-control equipments but also with automatic illuminated circuit diagrams operating in close connection with the remote-control installation and showing the conditions at other stations. These dispatcher's offices are usually situated at one of the power stations or substations of the district, not only by reason of the past growth of the system, but also to save the cost of having to install the remote-control apparatus and connecting cables in a separate control station. The construction of the remote-control apparatus is generally similar to that of designs used for automatic telephone or telegraph systems, but with the addition of special safeguards against unreliability. Importance is attached to reports being automatically recorded with the date and time.

On town systems the results obtained are exceedingly good. Owing to the fact that every fault is reported automatically, it is possible on the average to reduce the time for its clearance by 20 minutes. In rural areas this reduction may be greater still. The average does not include cases in which the supply can be maintained simply by changing connections.

In systems supplying electric railways, remote-control direct from the load dispatcher is indispensable if heavy traffic is to be handled, not only because a delay of a few minutes will cause a disturbance of the whole traffic but principally because short-circuits are more frequent on railway installations than on other supply systems. The loss of time caused by telephone communication between the load dispatcher and the attendants on the several substations cannot be afforded. Incidentally, it may be mentioned that the cost of construction of metropolitan railway systems can be much reduced by the employment of remote-control apparatus.

The examples given in the Appendix show how the problems of load dispatching have been solved in individual cases.

APPENDIX.

Examples of Load-Dispatching Plants.

*Berlin.**

The load-dispatching plant of the Berlin undertaking is the largest and best-equipped control system to be found on the Continent. The demand is of the type characteristic of large towns with a high density of load. Power is supplied mainly from the company's own steam-driven stations, and also to a great extent through 110-kV transmission lines from distant steam power stations fired with lignite.

The following are the generating capacities of the Berlin power stations: Klingenberg, 270 000 kW; Rummelsburg, 62 500 kW; Oberspree, 44 500 kW; Moabit, 84 400 kW; Charlottenburg, 54 000 kW; Westkraftwerk, 143 000 kW; Steglitz, 6 600 kW. The reserve capacity for dealing with peak loads consists of one power station equipped with a 20 000-kW Ruth steam-accumulator plant, as well as stand-by batteries. The Zschornewitz (540 000 kW), Trattendorf (160 000 kW), and Lauta (130 000 kW) power stations hold 127 000 kW at Berlin's disposal. They do not belong to Berlin, but form part of a 110-kV system extending to Silesia. The generating capacity of the whole interconnected system of the Berlin municipal undertaking exceeds 1 000 000 kW.

The Berlin Electricity Supply Co. supply energy to, and cover entirely or in part the requirements of, certain traction undertakings, e.g. the Berlin tramways and underground railway, and the electric urban rapid-transit railway. They also feed the smaller supply system of the South-West Electricity Supply Co. These two undertakings have separate district load-dispatching plants, to which reference will be made later.

The staff of the load dispatcher of the Berlin municipal undertaking consists of 1 chief engineer, 1 assistant engineer, 1 superintendent engineer, 5 shift engineers (each with 1 attendant and 1 skilled fitter), and 2 office assistants.

An account will now be given of the apparatus and equipment installed.

(*a*) *Telephone plant.*—This consists of private connections to all the power stations and main substations, and to several post office telephone exchanges. There are three control panels, two incorporated in the writing desk and one in a telephone cubicle.

The following items are of special interest. (1) Connections to post office telephone exchanges and to the undertaking's private branch exchanges and private automatic exchanges. To ensure freedom from disturbance, connections are made to two separate exchanges at each station. (2) Connection to the undertaking's private automatic exchanges at the power stations, with the possibility of intrusion. By the selection of a further special number on the dial, the load dispatcher is enabled to effect a connection with any other station even if the line is otherwise engaged.

* W. Fleischer: "Control Station of the Berlin Municipal Electric Supply Co., Ltd.," *Elektrotechnische Zeitschrift*, 1933, vol. 54, p. 49.
"Load-dispatching of the Berlin Municipal Electric Supply Co., *Elektrizitätswirtschaft*, 1929, Nos. 493 and 495, pp. 502 and 554.

This facility has proved very useful and of advantage in cases of emergency. (3) Devices for ringing up the load dispatcher. In emergencies it must be possible readily to communicate with the load-dispatcher's office. For this reason the normal dialling of 5 numbers is replaced by the simple dialling of a single number. The ease with which this connection can be effected has had a beneficial influence on the willingness of the attendants to report disturbances. (4) Direct telephonic connection with special apparatus at the most important points of operation of the supply system. These lines, which are operated by means of local batteries, are the ones which are the most frequently used. Great importance is therefore attached to quality of reception.

(*b*) *Tele-typewriters.*—Two tele-typewriters are provided, with connection to each important point of the system.

(*c*) *Remote-signalling plant.*—With this, the following instructions can be given to the peak-load stand-by stations: "Normal supply," "Emergency supply," "Cease supply!"

(*d*) *Main signalling plant.*—This connects with all power and transformer stations. The following signals can be transmitted, by means of drop indicators and luminous circuit diagrams: voltage fluctuations, fluctuations of frequency, earth leakage (100-kV system), earth leakage (30-kV system), emergency alarum at power stations, emergency alarum at transformer stations, relay room, failure of auxiliary voltage.

(*e*) *Regulation of frequency.*—The load-dispatcher's office is provided with a highly sensitive frequency meter and a synchronous electric-clock system. One machine on the system is fitted with an oil-pressure regulator, which maintains constant frequency to such an extent that the time shown by the synchronous clock does not deviate by more than 2 seconds in 24 hours.

(*f*) *Remote-metering plant.*—This is the most important part of the equipment so far as supervision of the load is concerned. It is operated on the impulse-frequency system. There are 56 metering points, 15 ink recorders, and 17 indicating instruments.

The individually-transmitted values can be cast up automatically in two groups in any desired combination, and to a total. The total is retransmitted to the power stations, so that each station knows, in addition to its own total, the total of the whole undertaking. According to a time table worked out by the load dispatcher, each power station supplies a certain percentage of the total power. The advantages of this method have already been explained. It will be of special interest to mention here that a system has been introduced which enables phantom indications to be made. By means of this, the load dispatcher is able to introduce a fictitious value of power which he may add to, or deduct from, the indicated total of the system. He can thus lead the stations to believe that the total power is higher or lower than it actually is, and thereby cause them to increase or decrease their load. This results in a decrease or increase of the load on the frequency-sustaining generators.

In addition to this main remote-metering plant, there is a second one for the purpose of indicating the several voltages of the entire system, and a third one—with 15 indicating instruments—for the supervision of the battery peak-load stations.

(*g*) *Other apparatus.*—Besides the equipment mentioned, a network compensator is installed to indicate the degree of compensation. According to the indications of this instrument, the earth-leakage coils of the entire system are adjusted. Finally, a suitably devised photometer is provided which records the intensity of the light of the northern sky.

*Load-Dispatching Plant of the Berlin Rapid-Transit Railway.**

This d.c. railway system is supplied with power from both the Berlin municipal undertaking and the Elektrowerke. The latter concern also supplies current to the former. The amount of energy the railway purchases from the Municipal undertaking is intended to be the same as that bought from the Elektrowerke. The municipal undertaking feeds the main switching stations through 30-kV underground cables, and the Elektrowerke feed the "West" transformer station through 100-kV overhead lines. The railway owns a 30-kV and a 3-kV underground-cable network. The system comprises 39 convertor and rectifier substations, of which 32 are unattended and remote-controlled. They are operated from 4 main control rooms and 1 load-dispatcher's office. Railway systems of this kind are usually so designed that direct current is fed directly from one or more central stations. In the present case, however, direct current is supplied by a large number of substations (each railway station having its own rectifier station). In contrast to the usual central feeding systems, there is therefore a subdivided d.c. feeding system.

The load-dispatcher's room is housed in the same building as the remote-control room, and is installed in a rotunda lighted by a skylight ceiling. The following are the duties of the load dispatcher. (1) Distribution of the power purchased from the municipal undertaking and the Elektrowerke (both supply on an average the same amount of energy in each month). (2) Giving of orders for the operation of the 30-kV cable network. (Orders are given by telephone, and operations are supervised by means of an automatic illuminated circuit diagram with 88 return signals.) (3) Giving of orders for the operation of the 3-kV cable network. (Orders are given by telephone with reference to the coloured diagram.) (4) Supervision of load on the 30-kV cable network: remote measurement of current—11 metering points, 11 ink recorders, and 11 indicating instruments of the "lighted band" type. (Besides these there are 11 ink recorders and 11 lighted-band instruments for local metering.) (5) Adjustment and supervision of all protective relays and overload circuit breakers. (6) Collection of reports concerning faults. (7) Issuing of daily, monthly, and annual reports regarding load conditions. (8) Control to ensure that supply contracts are fulfilled.

An account will now be given of the devices and apparatus installed.

(*a*) *Underground communication system.*—The cables for communication purposes are run in the ground along

* K. Riedel: "The Electric Supply System of the Berlin Stadt-, Ring- und Vorortbahnen," *Siemens Zeitschrift*, 1933, p. 544.

the track on the side opposite to that on which the power cables are laid. They are partially protected against the influence of the high voltage.

(*b*) *Telephone equipment.*—Two telephones are installed with direct connection to every important point of the entire railway system. Direct connection to the post office telephone exchange, as well as to the load dispatcher of the Berlin municipal undertaking, is also provided.

(*c*) *Remote-metering equipment.*—This operates on the potentiometer and impulse-frequency system. Ink recorders are placed on both sides of the automatic illuminated circuit diagram (11 on each side), and for convenience indicating instruments of the lighted-band type are mounted on the load-dispatcher's desk, opposite his seat.

(*d*) *Illuminated circuit diagram.*—The automatic diagram shows the 30-kV system, the important oil circuit breakers being represented by 88 back-indicating switches. The diagram is thus a manually-operated illuminated position indicator which simultaneously acts as the control switch for the remote operation of the circuit breakers. All cables under electrical pressure are indicated by the illumination of the corresponding strips on the circuit diagram.

The load-dispatcher's office is housed in the same building as the control room of the main switching station. In this control room are installed not only all apparatus and devices for the manipulation of the switching station itself, but also the devices for the remote control of 16 rectifier substations. Each rectifier station is represented by an automatic illuminated circuit diagram in which the control switches are incorporated, so that the substations represented can be manipulated from one panel. The connection between the control rooms and each rectifier substation is made by a 2-core cable.

In addition there are 3 other remote-control rooms for the remaining 16 unattended substations. The entire remote-control system contains about 500 control and 700 signalling possibilities.

Load-Dispatching plant of the South-West Electricity Supply Co., Berlin.

The total capacity of the generating stations of the South-West Supply Co. is relatively small, namely 85 000 kW (Schöneberg 13 000 kW, Wilmersdorf 72 000 kW). The system is connected to that of the Berlin municipal undertaking at a transformer station. On the whole, these two supply systems are very similar. On the South-West Supply Co.'s system the control of the generation of power is entirely automatic and is done by means of an automatic regulator. The incoming power from the municipal undertaking is metered at the transformer station, and the value is transmitted by a remote-metering device to the Wilmersdorf power station, where the load of the generators is automatically regulated in such a way that the supply from the municipal system does not exceed a predetermined value. The error of regulation is within 2 per cent.

The duties of the load dispatcher are essentially the same on this system as on the others which have already been described.

Load-Dispatching Plant of an Industrial District.

The supply network forms part of a large system in that district which supplies power from its own stations to a great many collieries, which both purchase and supply power. The exchange of power is covered by agreements, so that the remote-metering equipment is used not only for the distribution of power among the power stations owned by the undertaking, but also to supervise consumption and re-supply by the collieries. This relatively complicated supervision is necessary because the collieries have to cover their own requirements before supplying current to the system. Thus they cannot be relied upon to provide a regular supply.

Twenty-six remote-metered values are transmitted to the load-dispatcher's office. As this is situated at the main power station, the power generated at that station is also metered and cast-up with the other values to various part sums and to a total. Further, it is possible temporarily to separate from the others, to observe, and to record, the metered values transmitted from the collieries.

As on the extensive 10-kV underground-cable network earth faults are liable to occur through the failure of conductors owing to earth subsidences in the mines, practically every unattended substation is connected to the dispatcher's room by an automatic remote-signalling device which immediately reports the tripping of a circuit breaker. The system applied is similar to that of a fire-alarm. Each signal is recorded, with date and time, by telegraph apparatus, and very good results have been obtained by this method.

*Vienna.**

The supply afforded to the city of Vienna by the power stations of the municipality is very similar to that of the city of Berlin, except that the proportion of purchased current is much higher compared with the capacity of the municipality's plant. There are three steam power stations—Simmering (108 000 kW), Engertstrasse (60 000 kW), and Ebenfurth (35 000 kW)—with a total generating capacity of 203 000 kW. The last is a lignite-fired steam station, connected by 100-kV overhead lines of 90 km length to the 28-kV system of Vienna. The remainder of the power is purchased from two other companies, the Steirische Electricity Supply Co. and the Lower Austria Electricity Supply Co. It is interesting to note that the two high-voltage systems of South and West Austria are interconnected only through the 28-kV system of Vienna. According to the contracts, the power to be supplied by the Steirische Supply Co. is 35 000 kW and by the Lower Austria Co. 18 000 kW.

The following particulars relate to the supply by the former. Along the 100-kV line of this undertaking a large number of carbide works with greatly varying demands are supplied, and in consequence the power delivered to Vienna and the remainder to the system at one time fluctuated very considerably. To avoid this inconvenience, an automatic remote-controlled load regulator was installed. At the Ternitz transformer station, from which power is supplied to Vienna, a

* A. PETRICH: "The Load-Dispatching Station of the Vienna Municipal Electric Supply Department," *Elektrotechnik und Maschinenbau*, 1933, vol. 51, pp. 445 and 460.

remote-indicating wattmeter (impulse-frequency system) was installed; this was connected through a 70-km public telephone line to the Arnstein power station, where the regulator was installed. At Arnstein a 20 000-kVA set is so regulated as to take all fluctuations of power, thus protecting the Vienna system.

The load-dispatcher's office is housed in the main office building of the company. The duties and auxiliaries at the disposal of the load dispatcher are in general similar to those already described. The remote kW metering installation (impulse-frequency system) comprises 25 metering points fitted with 27 transmitters; and 5 indicating instruments and 11 ink recorders are installed on a panel in the load-dispatcher's office. Means for automatic summation are, of course, provided. In addition to the remote metering of kW, voltage remote-metering equipment extending to 7 metering points is installed (impulse compensation system). The automatic illuminated circuit diagram represents the whole system and indicates by coloured lights the conditions on the 28-kV busbars of all power and transformer stations. The positions of the switches are represented by indicators, manually operated according to reports received by telephone. Reserve batteries are controlled similarly by means of a machine telegraph with 10 positions, like those in Berlin.

*Oslo and Norway.**

The lay-out of the main Norwegian system is similar to that of Vienna. An eastern and a western high-voltage system fed from hydro-electric stations are interconnected solely through the Oslo 30-kV underground-cable network. Oslo itself possesses only one steam power station, the output of which is inconsiderable compared with that of the whole system. Fundamentally, however, there is a great difference between the supply systems of Vienna and of Oslo. Whilst in Vienna the municipal system is an independent system which is supplemented by power supplied by the two high-voltage systems of Austria, the Oslo municipal system is not independent but forms part of the whole system. It is therefore a very important link between the two high-voltage systems of Eastern and Western Norway.

All the Norwegian generating stations except that at Oslo are water-power stations. They are owned by 9 independent companies, which have formed an Association and since 1918 have set up a load-dispatcher service at Oslo. Before that, each company operated its own system and there was no possibility of equalizing the load according to the monthly and annual fluctuations of available water. This, however, was unsatisfactory, all the more so since the natural water storage was insufficient. It therefore became necessary for the supply companies of Eastern and Western Norway to assist one another and thus make full use of the quantities of water available in the various districts. In this manner the load-dispatching plant of the "Samkjöring" (the name of the Association) acts as a kind of clearing house for electrical power.

The capacity of the entire system is 500 000 kW, comprising the output of 18 water-power stations and 1 steam station. Each of the two 130-kV overland systems is connected and linked to the other through the Oslo 30-kV ring network. The latter network is therefore of special importance, and for this reason the auxiliary equipment of the load dispatcher is concentrated mainly in this part of the power-supply system of Norway.

Apart from the usual duties associated with his position, the Oslo load-dispatcher has to direct his attention particularly to the proper utilization of the available water. He must also ensure that the various agreements of the several companies regarding the water regulation of rivers and the rights of other users are properly carried out.

The variations in the quantity of water available for power generation make it necessary to distinguish between first-class power and second-class power. First-class power must be available at any time of the day and is comparatively expensive, whereas second-class power is available only when, at the time of demand, it can be generated. Consumers of second-class power are principally owners of electric furnaces and pulp factories. It is the duty of the load dispatcher to supervise the supply to the consumers of second-class power. By reason of these circumstances it has been found necessary to attach a publicity bureau to the load-dispatcher's office.

Telephone plant.—The Samkjöring possesses an extensive carrier-current telephone system giving access to all important power and transformer stations. The smaller stations of the supply system can be reached by means of the public telephone system. An extensively-branched telephone system covering in particular the Oslo ring network has been installed. All the apparatus for the telephones, with the necessary switches, is fitted in the load-dispatcher's writing desk. Priority is provided for all calls involving the load dispatcher.

Remote-metering installation.—The impulse-frequency system is confined mainly to the Oslo 30-kV network (Smestad and Toyen are the main transformer stations for the exchange of power between the eastern and western supply systems). There are on the system 12 metering points, 15 transmitting devices, 15 indicating instruments, and 2 ink recorders combined with devices for casting up the single values to each required partial sum and to a total.

In addition to this, the total of the metered output of the Nore power station is transmitted by a carrier-current impulse compensation system to Oslo.

Remote-control equipment.—All the main substations of the Oslo system can be remote-controlled by the load dispatcher, at whose office 36 remote-controlled and 213 signalling switches are installed on a large illuminated 12-panel circuit diagram 10 metres in length. The automatic diagram represents the whole of the Oslo system, the two high-voltage systems being represented only by painted extensions of the diagram.

Frequency regulation.—For the purpose of frequency regulation a frequency recorder in connection with a synchronous clock is used. After giving certain signals which have been agreed upon, a number of predetermined power stations can one after the other take over the stabilization of the frequency. The author does not know whether this method has proved satisfactory.

* A. B. Bjerknes: "Conjunctive Operation of the Electric Power Stations in South-East Norway," *Proceedings of the World Power Conference* (Sectional Meeting, Scandinavia), 1933, vol. 2, p. 455.

The Genoa Load-dispatching Station of the Italian State Railways.

This installation will only be briefly described as it is still under construction, but it must be mentioned because it represents a type and method which is unique on the Continent.

The Genoa load-dispatching station controls the supply to a main-line railway system, fed from a number of water-power stations belonging to different companies. The stations concerned utilize the water power derived from the southern watersheds of the Alps, and, as is well known, supply Upper Italy with power by means of long transmission lines.

The object of the load-dispatching plant is to control the supply of power to the railway from the various companies, and, by dividing the railway system into sections, to regulate the traffic in such a manner as to render the purchase of power as economical as possible. In view of the extent of the interconnected railway system, the distances to be bridged are very considerable. Owing to the fact that during several decades the railway system had developed considerably, the existing communication networks were such that interconnection of the kind required for load-dispatching work was not easy to achieve, and the problems to be solved by the designers of the remote-control and metering equipment were therefore difficult. Only one example of the difficulties met with will be given, to show how a load-dispatching project can be carried out even in seemingly impossible cases, at the same time keeping the cost within the bounds of economy by avoiding the installation of long new lines, the addition of highly subdivided high-frequency installations, and the use of public telephone lines (which cannot always be regarded as sufficiently reliable).

The example which will be considered is the line between Bologna and Genoa, which has a length of about 300 km. The line consists of an uninterrupted twin-core cable, and transmits continuously to Genoa two metered values each from Bologna, Pontremoli, Aulla, and Livorno. For the impulse-frequency system, voice-frequency transmission is adopted. The two values from Bologna are transmitted to Parma (90 km) over the 130-kV high-voltage overhead lines by means of modulated high-frequency carrier waves. The high-frequency receiver at Parma transmits the metering impulses through a twin-core underground cable to Pontremoli. The two values metered here are transmitted through a 9-km iron overhead line of 4-mm diameter to the underground cable, converted to different voice frequencies, and thence transmitted to Aulla, with the values from Bologna, through an underground cable of 21-km length. At Aulla, two further voice frequencies for two metered values are added, and the whole is transmitted through an underground cable to Spezia. Here, two metered values coming from Livorno over a 90-km iron overhead tie-line are transmitted also at two voice frequencies to the 2-wire core in the underground cable. From this point the eight frequencies are transmitted together through an overhead cable to Genoa, where the frequencies are separated and the impulses conducted to the respective indicating instruments. The transmitted values are added up automatically in groups and to a total. Remote control at great distances of the switching operations at the feeding stations on the Bologna–Florence rapid interurban railway will be adopted later on. It is also intended to transmit the positions of the railway signals to the load dispatcher.

It is evident that extensive investigations are necessary for the adaptation and adjustment of the transmitting and receiving apparatus on these lines, where conditions as to capacitance, inductance, leakage, and interference through cross-talk, differ greatly from the normal, and troubles may arise owing to the influence of high voltages.

Union d'Électricité, Paris.

This company supplies energy, in bulk only, to 8 supply undertakings, 3 railway systems, and the city of Paris. At present it owns only comparatively small generating stations. Two of these possess a combined installed capacity of 116 000 kW (Gennevilliers 36 000 kW, and Vitry-Nord 80 000 kW), and are used for the general supply. The Nanterre (20 000 kW) and Issy-les-Moulineux (20 000 kW) stations supply current for traction. There are, however, three large stations under construction, or proposed, of a combined installed capacity of 720 000 kW. Apart from these stations, energy from water power is obtained from the Massif power station, of which the installed capacity is 75 000 kW. As the supply areas of the undertakings to which it gives bulk supplies extend to Central France (Orléans), the company possesses an extensive high-tension overhead-line system, and this is connected to the 220-kV busbars in Central France. The supply to the Paris undertakings is given by means of a 60-kV cable system. This network (like that of Oslo) is at the same time a connecting link between the energy coming from the South and the energy generated in the northern supply areas. The main transformation point is at Villejuif.

The load-dispatching plant of the Union d'Électricité is situated at Rue de Messine, Paris, and the conditions to be fulfilled by it are similar to those of the control stations already dealt with. A remote-metering installation is provided for controlling the individual power stations, as well as for the regulation of the import and export of energy. For frequency-control purposes a recording frequency-meter in conjunction with a frequency timing clock is provided. All power stations, important switching stations, and traction substations, are connected to the load-dispatching station via their own communication networks. The load-dispatcher's control room is also provided with a large diagram showing the connections of the system and the positions of the oil circuit-breakers and isolating switches.

ACKNOWLEDGMENT.

The author desires to put on record the assistance which he has received from Mr. J. W. Rissik, B.Sc. (Eng.), in connection with the preparation of the paper.

[The discussion on this paper will be found on page 722.]

Discussion before The Institution, 3rd May, 1934.

Mr. J. D. Peattie: The author gives very little indication of one most important point, the cost of the arrangements he describes. The most important single item is the cost of the communication channels. He states that on the Continent, supply undertakings prefer to use their own private transmission lines rather than to hire Post Office lines. He also gives some interesting information showing the widespread use on the Continent of high-frequency carrier-current communication channels.

When the arrangements for control of the grid were under consideration, many alternatives were examined, and as a result the policy of making use of the existing national network by hiring private channels from the Post Office for the exclusive use of the Central Electricity Board was finally adopted. So far, there has been no reason to regret that decision. The Board have established seven control centres and from each of these single channels radiate to all the important grid points. These grid points are located throughout the country at varying distances from the control rooms, and in order to keep the cost to a minimum it is necessary to reduce to a minimum the number of channels allocated to each grid point.

So far those facilities only have been provided which can be conveniently obtained by the use of one channel only between the control room and each main grid point, but the problem is very different from that which faces an authority operating with an extensive cable system in a densely loaded urban area. In such a case the provision of communication pilots involves little additional expenditure, and it is possible to elaborate the communication system to a much greater extent without any great additional expense.

The stage of development at which a few engineers at a control centre control and operate the whole of the widespread system without any operators at the remote generating and transforming stations, has not yet been reached. So long as there are operators at the remote stations, it is essential to provide reliable telephone communication. The first essential feature of the communication system is, therefore, to furnish an efficient telephone service. In addition, on the grid, equipment has been provided to relieve the telephone traffic by making use of the hired channels to transmit certain indications which can be conveniently sent automatically. These indications are: the position of the main oil circuit-breakers, the tap positions on the main transformers, the load transfers over the grid transformers, the total loads sent out from certain generating stations, and the system voltage at a few important points. In addition, in the other direction, arrangements have been made to transmit from the control centres to certain generating stations a series of seven routine instructions.

The author lays most emphasis on the remote indication of meter readings. On the grid, provision has been made for this as indicated above, but at this stage of development considerable importance is attached to getting back to the control centres automatic indication of the switch positions, so that the control engineer can take action quickly in emergency.

The author apparently suggests that by some means total-load indicators will replace accurate frequency meters. I am inclined to question his arguments in this respect. It would seem that exactly the same difficulties with regard to accuracy will arise with the total-load indicators as with the frequency meters. As relative measurements of time can be made more accurately than relative measurements of loads, it appears that the solution of the difficulties is more likely to be found in development of methods of frequency or time measurement than of load measurement.

Mr. A. G. Shearer: I should like to take the opportunity of mentioning some progress that has been made on the North-East Coast with regard to the control of the North-Eastern Electric Supply Co.'s system. To all intents and purposes this system is operating comparatively simply, and yet under conditions which, owing to the large number of power stations (at one time they numbered 34), have necessitated certain complications of load and voltage regulation.

At the time the company introduced the control system in 1906, when 20 000-volt feeder cables were first being laid, it was realized that the control staff ought to be provided with first-hand information as to the voltage conditions on the system. As the system grew—it now has over 1 000 substations—and when the 66-kV feeders were first introduced in 1923, supervisory control and further indicating instruments became necessary for the guidance of the control engineers. The control staff have found it essential that there should be continuous indication in the control room of the load on the main power stations, but no attempt is made to indicate the load back from the smaller generating stations, mainly of the waste-heat type, running in parallel. Further, for the main feeders radiating from the three main power stations provision is now made to indicate the load, the power factor, and the switch positions. In the schemes that have been set before us by the author stress has been laid on the advisability of having an illuminated diagram. We, on the other hand, have developed the ordinary circuit diagram with hand-operated metal discs indicating the position of every automatic switch on the system. These number, at the present time, about 8 000.

With regard to supervisory control, I take it that operating engineers throughout this country will welcome any improvement in design, so long as it is absolutely reliably constructed, installed, and maintained; and that what has been said with regard to communications—that to a very large extent the reliability of a supervisory control is centred round the successful operation and maintenance of the telephone system—will find ready agreement among them.

Some years ago, in order to get the full benefit of all available assistance in the event of disturbance of the system, arrangements were made for consumers to appoint certain men who would immediately report back to the control office when switches had tripped. Full use has been made of those facilities. Some ten or twelve years ago arrangements were also made to indicate back, for the guidance of the control engineers,

not merely important points where switches had tripped, but also the order in which the switches had tripped. Control engineers attach great importance to that facility.

In dealing with emergency loads, the control staff notify the outside staff of gale warnings received by wireless. Thunderstorms in business hours often have the effect of increasing the load to the extent of some 10 000 kW. Bearing in mind the improvement in the standard of communications, I should like to ask the author whether, on the Continent, any real progress has been made with the use of wireless apparatus for rural areas. Are there any facilities on rural lines on the Continent for indicating the position of earth faults? It should be remembered that these lines are erected as cheaply as possible, and that facilities for automatic communication add appreciably to the cost. With regard to the diagram shown on the screen in connection with electric railways, I should like to ask the author, concerning the 32 unattended stations on the Berlin Rapid Transit Railway, what provision is made for guiding the control engineer in order to ensure that each station is maintaining its correct share of the load. As to the control of frequency referred to in the paper at length by the author, it has been the practice of my company to delegate that duty to the operator at the base-load power station, who is supplied with the correct load for which each of the other power stations has to stand by. A system of morse signalling has been adopted between the principal stations, which enables the operator to keep the deviation from standard down to the minimum.

Mr. W. S. Burge: It is difficult to discuss a subject such as this, because the conditions of interconnected systems vary over such a wide range that the designs of the control rooms and the organization of the work involved often have little in common. The system described in the paper, for instance, relates to some few power stations in the ownership of one authority, whereas in the city of London we have a control centre operating the interconnection of some 50 stations in the ownership of nearly as many authorities. The commercial policies behind these two classes of systems are, of course, widely different, and this plays an important part in the equipments of the respective control rooms.

In the system described in the paper, stress is laid on the importance of remote-controlled switching from the control room, and no mention is made of any human link between the control room and the power stations concerned. In this system, the function of the control room is very similar to that of the individual undertaking's control rooms operating in liaison with the central control room at Bankside, London.

Between Bankside and the interconnected power stations there is a link of section or field engineers for organizing maintenance and inspection work, and no fully automatic switching is carried out from the control room. Switching can only be done on instruction from the control engineer, and he is entirely responsible for it, but the physical operation is carried out by the power-station staffs or the section engineers. The recording of switch positions is, however, automatic, and taken back to the central control room at Bankside. Even in this respect, however, the organization of the control room requires a manual repetition of the fresh switch position after it has been automatically transmitted to the control room.

In the control room of this system the organization of the loading programmes and the running shift duties of the interconnected power stations play an important part. The control engineer is responsible for bringing in fresh relays of power stations to meet the quickly-rising early morning load, which will build up from 300 to 900 MW in about 90 minutes. The winter evening peak of about 1 600 MW also has to be followed by the rapid closing-down of a large number of stations, till finally the base load of about 300 MW is reached. The control engineer in this sort of control room therefore has many other duties to perform apart from load dispatching. In the working equipment of the control room we rely mainly—as Mr. Peattie has pointed out—on the telephone and the automatic indication of switch positions.

Mr. M. S. Mason: We have embarked on a grid for supplying electricity to the whole of the country, and from that grid we are transmitting current via secondary sources, through power companies and municipal undertakings. The grid, as we have heard, has supervisory control of its supply. Not many of our power companies, I am afraid, have such control, and that lack, we have heard, may be chiefly due to the cost. I would submit that we in this country have to face the question of reliability of supply. While we may not be able to man substations, supervisory control can go a long way towards meeting that situation. I installed in my comparatively small area three years ago a system of supervisory control which I think is completely new. It has in its sending the same principles as those referred to in the paper, but the check-back is by means of potential, which lessens the cost to about one-quarter. When we were putting out quotations for this supervisory system, the cost was found to be prohibitive, but the system which I installed, and which has worked without any trouble, has allowed us to extend it at the present time and to use it to the benefit of the consumer.

There is, however, one problem which is holding up that development, and it is possibly one of the largest of the questions which are hindering the power companies in their development along the same lines: that is the means of connecting between the control station and the various substations. The grid, I believe, uses the telephone system, and valuable revenue is available to the Post Office authorities if they will only make their terms reasonable; and then not only the power companies but also the larger municipal undertakings with rural districts will use their lines.

Mr. W. H. Steele: I am particularly interested in the methods adopted by the Berlin undertaking for allocating the various loads and dealing with peak conditions. It appears that this and the other systems mentioned in the paper consist of large stations and units; hence the necessity for special methods and apparatus for dealing with rapidly rising loads.

In this country the large majority of interconnected systems possess a large measure of small plant which is quickly available to deal with sudden load-changes.

When, however, this plant is permanently closed down, it is evident that measures will have to be adopted to deal with these changes, the alternative being an unnecessary large provision of running stand-by plant. Although pulverized fuel and automatic control may possibly be the solution from the boiler-house aspect, there is still this point to be considered from the generation aspect. The allocation of loadings given hours in advance will, of course, provide a solution for the ordinary daily load changes; but sudden thunder-storms, rain-clouds, and fog, cannot be dealt with in this manner, for the increased load which results must be dealt with in a matter of minutes.

I have obtained some figures for the rise of load in this district towards the end of January: they show a rise of the order of 4 or 5 MW per minute for the early morning rising load, taking place over 3 hours. The evening peak, however, rises at the rate of some 7 or 8 MW per minute over a shorter period. These readings, however, are printometer readings; spot readings would have shown a steeper rise over the shorter periods. A recent rainstorm in this area caused an increase of load of 175 MW in 15 minutes, or approximately 11·5 MW per minute. This was dealt with not by variation of frequency but with the assistance of the spare capacity of a large number of smaller machines, although 75-MW sets were in service at the time.

I note the method adopted in Berlin to obtain the various light values. I should like to know whether any definite relation has been established between these values and the actual loadings resulting therefrom, also what methods are adopted to ascertain the extent of a thundercloud or fog area. Has the author established any relation between temperature and loads?

He appears to be strongly in favour of high-speed summation or direct metering in the control room; this seems to be desirable, at any rate on the larger or base-load stations, if the maximum economy is to be practised.

It would be interesting to know why Post Office lines are not used on the Continent.

Captain H. C. Hannam-Clark: From the communication engineers' point of view, the point in the paper which is perhaps of the greatest interest is the number of extra facilities described as indispensable but not in use in this country; further, the Continental engineers appear to be provided with a much larger number of communication channels than is usual in British practice.

The author lays stress on the necessity for speed in the transmission, summation, and indication, of his meter readings; he appears, however, to be slightly self-contradictory in that later on he says that the load dispatcher must not, except in cases of extreme emergency, operate any switches himself, but must give his orders by the much slower and less precise method of telephone speech. He also lays stress on the necessity for good quality of reception, and discusses the advantages of locating the load dispatcher in a power station with a view to economy in communication plant. In our experience this question of the effect of noise upon the load dispatcher has not been given full consideration. In noisy power stations where the load dispatcher is located, a silence cabinet is provided or a telephone is placed in a room close by. This provision does not appear quite to meet the case, for the effect of the noise disturbance seems to continue when the load dispatcher walks into the other room. For several minutes—the length of time varying according to his temperament—he is unable to make satisfactory use of his telephone. We know of one case in which the local control engineers prefer to walk across the road to a public telephone kiosk and to speak from there! Having tested this line and carried out experiments in the silence cabinet, we are all satisfied that the trouble is due to a nervous disturbance which will only be overcome by locating the load dispatcher in a really silent place.

I should like to refer to a rather interesting communication arrangement on the system of the Grampian Electric Supply Co., where three different types of communication channel are used: carrier current, earth-wire and pilot cable, and Post Office line. There are two duplex carrier channels, one operated on a 33-kV line between Tummel and Rannoch (both of which are hydro-electric stations), and another on a 132-kV line from Tummel to Abernethy, where the Grampian Co.'s lines join up with the grid, and also supply Perth and the local network. Between Abernethy and Perth is a 2-pair armoured pilot cable which is erected on the 33-kV line in place of the usual earth wire. Tummel is the controlling station of this system, and between Tummel and Rannoch telephony is the only means of communication provided at present, though provision is made for enabling Rannoch to be remote-controlled from Tummel. Between Tummel and Abernethy, in addition to telephone communication, there is an extensive system of remote control, and, of course, remote indication and metering from Abernethy. The main switches controlling the connection of the 132-kV line to the grid are remotely operated by carrier current from Tummel. There is a small automatic exchange at Abernethy where the carrier channel from Tummel, the earth-wire and pilot telephone from Perth, and the C.E.B. circuit to Glasgow over a Post Office line, are all joined up, and there is full automatic intercommunication between the stations so joined. There are also, of course, special facilities to enable the important stations to break in on communications in case of emergency. The earth-wire pilot from Perth to Abernethy, in addition to providing a telephone circuit, provides two Translay feeder protection circuits, one for each of the two 33-kV circuits, on the line on which it is run. It is perhaps early to speak of the reliability of that earth-wire pilot. It is, I think, the first with that number of conductors to be erected, and it has only had to stand through one winter. As regards carrier current, however, there has been for over 3 years a telephone channel from Abernethy via Tummel to Rannoch on 132-kV conductors, and during those 3 years there has not been a single failure due to storms.

Mr. T. G. N. Haldane: It seems to me, broadly, that on the Continent more attention is paid to remote metering, and perhaps rather less on the whole to automatic switch indication. For instance, in the control room at Brauweiler the switch indications are put on the board by hand. In the control of the grid, automatic switch indication has, of course, taken the

first place, and metering is definitely relegated to a secondary position.

Perhaps the position could broadly be described in this way. Here we are at the moment primarily concerned with reliability and rather less with economy. When I refer to economy I am not speaking of the main economy resulting from the grid, but to getting the last ounce of economy out of an interconnected system. It is not improbable that the relative importance of this last ounce of economy will, in the future, become rather greater, in which case it is possible that a comprehensive and comparatively elaborate system of remote metering such as the author has outlined, or possibly a system of automatic load and frequency control will be adopted.

It should be borne in mind, however, that the grid represents a larger and more complex system than the majority of interconnected systems on the Continent. That fact is not, perhaps, always realized. For instance, the S.E. England system involves the control of something like 2 million kW of plant installed, about 1 000 miles of line and cable, and some 600 switches. The present order of importance of the control equipment is, as has already been pointed out, firstly telephony, secondly automatic switch indication, and thirdly metering. The metering, however, is confined to the metering of the import and export from the grid to the various stations.

I should like to ask the author whether he thinks that the comparatively complicated systems of remote metering used on the Continent are not to some extent the result of the existence of a number of financially independent companies and authorities, who, although they are associated by means of an interconnected system, require, because of their financial independence, complications in remote metering which possibly would not be necessary if the control were unified and in the hands of one public body.

At various points in the paper reference is made to the adjustment of earth leakage. No doubt this complication is due to the Petersen earthing system. We avoid this complication here, of course, because of our use of direct earthing.

It is very interesting to see the speed with which carrier-wave communication is developing. I should like to ask what the author considers in practice to be the shortest distance for which carrier-wave communication is economically feasible.

I am very much interested and a little amused at the description of the phantom load and fictitious indication on page 720. The system seems slightly immoral; power stations are given information which is incorrect in the hope of getting them to raise or lower their output in consequence. No doubt that is a system which may be very useful to central control engineers in certain circumstances!

I should like to ask for further particulars with regard to the emergency alarums referred to at the top of page 720, in connection with the Berlin load centre. I should like to know what these alarums are.

Mr. S. B. Jackson (*communicated*): The art of power-system control has developed largely as a result of local-system considerations. These have been so diverse that standardization of methods has been impossible. The continuously changing circumstances of electricity supply render such standardization difficult. Each system must therefore be dealt with upon its merits and the peculiarities attaching to it.

Referring to load forecasting, it would appear from the paper that this is not very difficult, but such is not the case in practice. Load depends upon so many variable considerations, and it does not seem possible to predict it within 1 to 2 per cent. On a very large system such as the South-East England Scheme, this may represent 20 000 to 30 000 kW, and at the present time only rough rules for load prediction are available. It would have been of interest had the method of load prediction been given, and also how load varies with given conditions such as weather, temperature, illumination, etc. Regarding the latter, one of the difficulties in South-East England, apart from occasional general dull weather, is the extremely local nature of the majority of dark-cloud conditions. Clouds in one part of the area may produce three or four times as much load as in another. Under such conditions, the sites of photometric cells must be judiciously determined, in order to enable the majority of weather conditions to be dealt with. Similarly, temperature variations over the area are quite appreciable. This is to be expected, as the area is approximately 160 miles long. Diurnal variations of 6 to 8 deg. F. normally occur. A recent observation is as follows:—

Place	Minimum night temperature °F.	Maximum day temperature °F.
Yarmouth	43	67
London	41	56
Worthing	38	60
Eastbourne ..	39	57

The minimum night temperature has varied by as much as 15 deg. F. between one place and another in the area, and in addition temperatures during the day may fluctuate with considerable rapidity. It would seem extremely difficult to create a rational method of load prediction, except by a long and tedious analysis of all the factors involved.

In connection with the number of machine starts, it is of interest to note the remarkable flexibility of modern plant, as demonstrated by the performance of the 1 400-lb. per sq. in. boiler and compound turbo-generator equipment at the San Francisco ("A") station. Two 50 000-kW machines are normally in stand-by service to a large system running at about 5 000 kW. Pick-up tests show that the turbo-generators can increase their output from 10 000 to 50 000 kW in 36 sec., and to 55 000 kW in 50 sec., without any instability as between the high- and low-pressure sections. The rate of picking up load may therefore be taken to be dependent on the temperature of the turbine casing, etc., and, provided the normal working temperature has been reached, no ill effects from sudden applications of load need be expected. Single-shaft units may be considered superior to compound machines in this respect.

On the other hand, a 60 000-kW machine was brought up to speed in 30 minutes, and it reached full load 20 minutes after being synchronized. A 30 000-kW

machine was brought up to full speed from cold in 7½ minutes, and full load was obtained 6½ minutes after the machine was connected to the busbars. Admitting that these machines are smaller than those to which reference is made in the paper, controversial questions on cold versus hot starting are nevertheless raised. The problem is of some importance, and the author's views upon it would be welcome.

As mentioned by the author, a very serious problem in regard to interconnected systems is the maintenance of correct frequency. Apart from the operation of stations on predetermined load programmes, there would appear to be some necessity for standard governor characteristics and closer regulation of steam pressure to variations of system loading. On the occurrence of system disturbances, when the changes of loading are very rapid, human operation is severely tested. Automatic boiler control seems desirable, because the prompt response of automatic equipment not only facilitates dealing with abnormal conditions but also enables small variations of loading to be easily detected. System flexibility is thereby improved, and the concern of the control engineers for load distribution considerably relieved, enabling them to deal with disturbance conditions more rapidly.

Regarding the difficulty of obtaining a reasonably accurate frequency indicator, a British instrument has recently been put on the market, registering 48 to 52 cycles per sec. on a scale of 41 in. This corresponds to approximately 0·002 cycle per sec. per mm of scale length.

The problem of dealing economically with the peak has yet to be solved. An interesting German development is the provision of ample storage capacity in the boiler itself and the operation of the boiler at a pressure higher than the main pressure, an automatic reducing valve being introduced between the boiler and the main steam range. I should be glad if the author could furnish particulars of this installation and details as to its success.

Mr. K. E. Latimer (*communicated*): The author has mentioned that great importance is attached to the quality of reception on some of the telephone lines. I should like to ask what are the normal standards of telephone transmission adopted on the Continent for this class of work; in particular, what attenuation is allowable between instruments, and whether any limit is set for line or room noise.

In this country it is usual to apply high-voltage protection to all communication circuits entering power stations. Such protection is mentioned in the paper, but it is not stated whether it is generally applied; nor is it explained how the signalling currents for the remote control and indication systems are transmitted past the insulating transformers which are presumably used to protect the telephones. It would be interesting to have some further information on these points.

There is a certain tendency for the staff of a power station to be unwilling to use the telephone after the occurrence of a serious fault, owing to the possibility of a contact between the power and communication systems I have noticed the same tendency on the part of the signalling staff of an electrified railway in Italy; confidence was restored to some extent in this instance by arranging the telephone on an insulating platform so that even if such a contact occurred the user would be fairly safe. In noisy power stations where the telephone has in any case to be placed in a silent booth such precautions would be easy to apply, and even when the telephone is installed in a control room the addition of a separate insulated telephone for use in emergencies might be an advantage and lead to greater sense of security.

Dr. Ing. M. Schleicher (*in reply*): Before replying to individual questions I propose to deal with a number of points raised by various speakers and covering the same ground. Briefly these are:—

(1) What is the relative importance of frequency control and remote metering of energy?

(2) Why such great importance is attached to remote metering on the Continent.

(3) Why does the high-frequency system find such favour on the Continent for transmitting indications over high-tension lines, and what is the position in that connection with regard to economy and reliability?

As regards the first question I fear that I have perhaps not made myself sufficiently clear. I consider that a remote metering equipment for the real and reactive load conditions of the system is not a substitute for, but is supplementary to, arrangements for frequency measurement or control, and I agree with Mr. Peattie that modern frequency-measuring instruments are very accurate and reliable. In this connection it may be pointed out that on the Continent frequency meters working on the resonance principle are in operation in which 0·005 period per sec. corresponds to a minimum scale division of 1 mm. Formerly, when relatively small networks and small power stations were in operation, a fall in the frequency indicated that somewhere an increase in load was taking place, and that therefore the power stations had to supply more power. In such relatively small systems it was easy to determine what had to be done to meet the extra demand, and it was a simple matter to give telephone instructions to that power station which was to supply the extra load required to restore the normal frequency. Under present-day conditions, however, there are two reasons why the procedure is different; in the first place it is usual to allot the maintenance of constant frequency to the larger power stations, but no matter how sensitive a frequency meter is used, the smaller power stations can no longer detect that the total load in the network is increasing. There is no alternative, therefore, for the smaller power stations but to adhere to their prescribed programme, or to wait until they receive a telephonic communication. The second reason is that in extensive networks, any abnormally large load in the total system often has its origin in local phenomena, such as morning fogs in any district of the whole area, or clouds, or, again, it may happen that certain industrial districts may be developing an abnormally high demand.

Let us assume that all power stations whose generating costs are approximately the same are arranged in groups. In such cases it would be more logical to transmit the

extra energy required from power stations in the affected area than to import the energy, for hours, over scores of miles, from a large distant station which is maintaining the frequency constant.

I am of the opinion that it is only by means of remote indicating equipment that the local stations are enabled to know whether they are importing a normal or abnormal amount of energy from the main network, and in the latter case to realize that they should export more energy, for the main network is coupled to the local networks at several points which do not coincide with the local power stations owned by the same company.

It is incorrect to assume that remote metering finds favour on the Continent only because so many networks, belonging to different authorities, mutually exchange energy, and that they merely desire to know how much is given and how much is taken; on the contrary the greater number of the existing remote-metering installations are intended to ensure the co-operation of the local power stations owned by the same company.

It might be contended that it ought to be possible to achieve satisfactory co-operation by means of disciplined co-ordination. It has already been pointed out that the frequency meter no longer indicates whether the load is increasing or diminishing. It should also be borne in mind that hydro-electric stations constitute no inconsiderable part of the total supply, and that many of these stations utilize the energy from mountain streams. Thus the energy supply fluctuates greatly with the quantity of water, since no water-storage reservoirs are available, and the water has to be consumed as it arrives.

If it is further borne in mind that every power station is called upon to cover the needs of its immediate supply area, then it will be realized that a remote-metering installation is a really valuable means for ensuring satisfactory co-operation of the various stations. I admit that these refinements are only necessary when the first consideration is to achieve maximum economy of operation, but it should not be overlooked that in most cases met with in practice the cost of installation of remote-metering equipment is small in comparison with the economies achieved.

To obtain a comparison which will give an insight into the question of cost consider the following: A high-frequency remote-metering channel over a 100-kV transmission line of, say, 100 miles long, costs, taking everything into account, as much as $\frac{1}{4}$ mile of the transmission line itself. A suitable telephone connection (two stations) costs as much as some $\frac{1}{2}$ to $\frac{3}{4}$ mile of the transmission line. In the case of future extensions the range of communication can, however, be increased to 100–150 miles without additional cost by means of the apparatus already available. The average length of the communication channels met with in practice is, however, generally in the region of 60 miles. The cost of valve renewals amounts to about £12 per annum for such a remote-metering installation, while for a communication system by means of telephone the cost of renewals would be some £16 per annum.

In general, high-frequency channels are common on transmission lines of from 220 kV down to 60 kV. Only recently has the system been applied to 20- to 30-kV lines. The reason why high-frequency communication was not applied until recently to the lower-voltage lines is not so much that, owing to the smaller cross-sections of these lines, the range of communication is shorter, but that the lower-voltage systems are more closely interconnected and therefore require a relatively greater number of chokes, thus increasing the cost of installation. The general opinion is that high-frequency communications are not only economic but also very reliable, and that defects are readily remedied, since faults can only arise in the transmitter or receiver, which are easily accessible. The majority of faults (defective valves) can be put right by unskilled personnel. The time and labour involved in locating faults in underground cables is eliminated. Moreover, it is common knowledge that communication is maintained even when the high-tension line is broken at one point, and that it is possible, during repair, to communicate with stations by coupling portable apparatus to the line. These are very important advantages, especially in sparsely populated or mountainous areas. The average number of conversations transmitted per station is in the neighbourhood of 100 to 400 per day.

We now come to another question raised during the discussion. Why is it that although on the Continent primary importance is attached to the maximum possible speed of transmission of the indication, the load dispatcher does not himself carry out any operations by means of remote control? The advantage of rapid transmission of metering indications is that it enables the load dispatcher to form at once a mental picture of what is happening, and it further shows the faults in their incipient state. This will be admitted by those who are accustomed to analyse the results of recording instruments. In addition, summation of load indications is possible when desired.

By this means faults which are gradually developing can be anticipated in many cases by reason of abnormal load increments, fluctuations, etc. Thus the load dispatcher is able to take precautionary measures by obtaining advance information from various points in the supply areas, and has time to arrange for power stations to stand by at points nearest to the place where the trouble is developing. At the same time he can choose the most economical stations for this purpose. When extra load is suddenly required the load dispatcher will choose such machines to be started up as have not long been shut down and are still warm. It can thus be seen that he is in the most favourable position to decide what are the most economical steps to take, and he should not therefore be expected to carry out the actual switching operations.

Some people imagine that if suitable television systems existed whereby the load dispatcher could see at will the switch positions at any of the stations, as well as the readings of the instruments, he would then be in an ideal position to carry out his duties. This is illusory, since he would then be faced with so much detail that it would be impossible for him to make rapid decisions. He is only interested in important readings and switch positions, and not in small details.

Mr. Peattie asks the cost of load-dispatching plant.

This is a somewhat difficult question to answer. On the Continent the rental for Post Office trunk lines connected by cable is in the region of 16s. per mile per month. The cost of remote metering, control, or signalling equipment, depends on the density of traffic of the channel. Given suitable lines it is possible, by adopting voice-frequency methods, to obtain 12 to 16 channels, each of which in turn is capable of transmitting a number of functions. The rental of the line is not affected thereby. I agree with Mr. Peattie that one cannot leave large 100-kV stations unattended. In such cases, therefore, remote metering, and back indications, as well as telephone communication, are sufficient. Such stations are not left unattended because many thousands of kilowatts of energy are transmitted, and they are of first importance with regard to reliability of service; further, because they constitute the base for the repair gangs responsible for the primary and secondary systems connected to them. This, however, does not mean that I consider remote control systems to be unreliable. This is not so, but as yet it is not possible to effect maintenance and repairs by remote control. Periodic tests and continuous local supervision of the entire equipment for transmission, transformation, and switching, as well as the mechanical operation of the most important stations, are the best guarantee to ensure reliable service on our large systems. At these stations, therefore, a certain number of personnel is always available for immediate dispatch to the place where trouble has been experienced. On the other hand, there is always a very large number of relatively small stations which can be safely left unattended. These should be remote-controlled.

I agree with Mr. Shearer that, in a large system, it is not necessary to telemeter the load of subordinate power stations. Illuminated circuit diagrams are not merely luminous diagrams but are characterized by the fact that, as it were, they do the thinking for us. The arrangement is such, that when a circuit breaker closes, everything in the circuit diagram lights up which corresponds to the actual parts of the network that the closure of the circuit breaker has caused to become alive. It is thus possible to see at a glance the result of the change without first having to watch the various switch-position indicators and then to build up a mental picture of the result. This, indeed, is a great advantage. The price of such equipment is only 20 per cent higher than that of the ordinary switch panels with position indicators only, but this extra cost is more than justified in cases of complicated networks. I should like to assure Mr. Shearer that, for system operation, control equipment of present-day design can be absolutely relied upon. As an example the oldest installation of supervisory control on the Continent, i.e. the application of supervisory control on a large scale at the Berlin Stadt- und Ringbahn, may be mentioned. Without any faulty operation, even during the one mishap which occurred due to a nail having been inadvertently driven into one of the pilot cables, about 1 million switching operations, 2 million indications, and 4 million instrument readings, have been transmitted. Only two electricians are required for the maintenance of the 75 equipments installed in this electrified railway system.

I understand that the company with which Mr. Shearer is associated has introduced a remote supervisory control system which immediately indicates the opening of circuit breakers in the sequence in which they occur. Such arrangements exist also on the Continent, and the experience gained shows that on the average the duration of any interruption of service is thereby reduced by some 20 minutes. I should like to know whether Mr. Shearer has gained similar experience.

On the Continent private transmission channels are preferred to Post Office lines, to avoid the maintenance of a reliable electric supply being affected by the density of traffic and the reliability of the Post Office installation.

In rural areas the main 25-kV distribution networks have been equipped, here and there, with high-frequency transmission; a definite start is now being made on the extension of these channels. Many of these networks have been equipped with earth-fault directional relays, the position of which enables the line to earth to be traced at attended stations. The stations of the Berlin Stadt- und Ringbahn are all coupled on the d.c. side and equally spaced, so that overloading rarely occurs. In addition the load on each rectifier can be read at any time at any of the stations by merely pressing a button at the dispatcher's room.

In reply to Mr. Burge, as the question of remote control covers such a wide field and as every supply system has its own peculiar conditions to contend with, it is difficult to judge in favour of one particular method of control, and I therefore described a number of systems in the paper. I was surprised to learn that in London, with its large number of machines and heavy load fluctuations, the supply engineers have managed to carry on, almost exclusively, by means of telephone communications.

It would be interesting to know whether the responsible authorities realize how much money could be saved in reduced fuel consumption and in reduction of stand-by plant, by the introduction of a good modern system of communication, bearing in mind that at present rather a large number of reserve machines is available.

In reply to Mr. Mason, I have always found that, with regard to cost, remote metering and load-dispatching have justified themselves, and that even simple remote-measuring installations, which at first were installed in order that the equipment might be up to date, were found later to be indispensable. It can be definitely said that remote-controlled stations are a paying proposition, and I recommend that whenever a new station is to be built an estimate should always be made of its cost when laid out for unattended operation and deliberately so designed as to be definitely unsuitable for the accommodation of personnel.

As a result of many years of experience I have found that, with remote control systems, whereby the chief consideration is to maintain definite values of pressure or current in the lines, it is impossible to be too careful with regard to refinements, since every line fault will sooner or later lead to an interruption of the supply, and its anticipation by means of suitable apparatus is therefore worth while. I admit that the control cables to the central control station constitute the greatest item of expenditure, but it should be borne in mind that

such cost becomes small if the pilot cable is always drawn in with the main cable when extensions are made.

In reply to Mr. Steele, observations of the light intensity of the sky are still in the experimental stage and I am not yet in possession of any results. The same applies to the effect of external air temperatures on the load (see also my reply to Mr. Jackson). Experiments are, however, being carried out in several places.

In reply to Capt. Hannan-Clark, the requirements of rapid indication of values, and at the same time slow switch-position indication, by means of telephone communication, are in no way contradictory. The chief object of remote metering is to operate a supply on economical lines, and to be able to follow all load fluctuations. During only a few hours in the year do disturbances occur; these can generally be dealt with by effecting certain switching operations. To be able to converse by telephone it is essential to eliminate noise, hence the telephone booth. I can only recommend the installation of the load dispatcher's control room in a power station if the cost of the installation would thereby be materially reduced, otherwise it should be placed elsewhere. The diagrams give the following signalling indications: Voltage fluctuations, frequency fluctuations, failure of auxiliary supply, earth faults on the 100-kV side, earth faults on the 30-kV side, and aural indications of disturbances at the power stations and at the transformer stations.

I agree with Mr. Haldane that the British grid is an achievement which has gained the admiration of the whole world. In the first part of my reply I dealt with the importance of remote metering. Doubtless the system of dealing with earth faults by means of arc-quenching transformers involves a certain amount of work, but its advantages are nevertheless very great, and it is found that the number of line faults which would affect the continuity of electric supply has been reduced to one-eighth by this method, at any rate in comparison with American supply systems in so far as published information is available.

It is true that phantom indications are, in a sense, "immoral," but it will be agreed that such "immorality" does not harm anyone, and at the same time it has its advantages.

High-frequency transmission of indications becomes economical over lengths of 30 km and upwards.

I agree with Mr. Jackson that, where extensive electric heating for buildings is concerned, the temperature variations in the various areas supplied with electrical energy must be as carefully watched as variations in the light intensity of the sky. So far as I am aware no published matter exists in this connection. Information may possibly be available from the Swiss electric supply undertakings, and also from those in Sweden or Norway, since in those countries current from hydro-electric installations is sold at cheap rates, and it may therefore be assumed that electric heating is carried out on a much larger scale than elsewhere. On the other hand the need for off-peak load is not so great in those countries, since the water is always available and machines can be started up immediately.

With regard to the question of the starting-up time of turbines, the figures mentioned in the paper refer to large machines. On the whole it can be said that equipment for giving an initial speed to already pre-heated turbines tends to reduce the starting-up time. It might also be mentioned that turbines of the radial-flow type can be started up much more rapidly than machines of orthodox design. I have no information in regard to any special arrangements of the stop-valve.

In reply to Mr. Latimer, on the Continent an accuracy of transmission of $\pm$ 2 per cent of the scale value is considered good, although there are installations which show a greater accuracy in spite of extensive summation. In the case of ordinary Post Office telephones the interference voltage should not exceed 5 millivolts, and for a good private telephone it should not exceed 30 millivolts. An interference voltage of 60 millivolts is considered bad.

Insulated platforms and/or insulating transformers at the beginning of a telephone line are compulsory in most countries on the Continent, and at any rate are usual. The latter are insulated up to 7 000 volts, depending on the type of line, and in front of them are provided a number of coarse and fine surge absorbers. Such arrangements are also in use on high-frequency transmissions, where the coupling condenser might break down. No cases of fatality have come to my knowledge. In a number of countries insulated speaking tubes and mats are in use, but these are no longer used on modern installations.

THE EFFECTS OF ELECTRODES ON MEASUREMENTS OF PERMITTIVITY AND POWER FACTOR ON INSULATING MATERIALS IN SHEET FORM.*

By L. HARTSHORN, D.Sc., W. H. WARD, B.Eng., B. A. SHARPE, B.Eng., Graduate, and B. J. O'KANE, B.Eng., Graduate.

(*Paper received* 16*th February*, 1934.)

SUMMARY.

Measurements of permittivity and power factor made on sheet materials with different electrodes are apt to give widely different results. The way in which these discrepancies depend on the properties of the contact film between the electrode and the sample is investigated with particular reference to tests at audio and radio frequencies, and it is shown that in certain cases electrodes consisting of graphite and brass plates in the form frequently used, give rise to very large errors. In particular cases such errors may be very large at audio frequencies and small at radio frequencies, or vice versa.

Mercury electrodes are considered to be the most satisfactory for general purposes, although a film of graphite between the mercury and the sample may improve the contact slightly, as previously noted by Churcher. Thin tinfoil applied with a trace of vaseline as an adhesive is a good substitute. Graphite electrodes backed with metal plates are easy to apply, but should be used with caution at audio frequencies, and not at all at radio frequencies.

INTRODUCTION.

A knowledge of the permittivity and power factor of insulating materials is becoming of increasing importance, as is evident from the fact that such measurements are frequently called for in standard specifications. On the purely electrical side, the measurements of capacitance and power factor may readily be made with high precision, but all who have compared the results of measurements on various materials under different conditions will know that the values obtained are liable to be greatly affected by the nature of the electrodes used, and in such cases they are obviously no safe guide to the properties of the material itself.

A considerable amount of information is already available concerning the properties of electrode contacts and their effects on insulation testing. A summary of that obtained previous to 1924 has already been given by Hartshorn,† and in that year Barlow‡ suggested that the contact resistance obtained with mercury electrodes is so great as to make their use questionable. Hartshorn§ has pointed out that any such contact resistance must be associated with a capacitance, and that the combination may account for some of the phenomena of absorption. Following these lines of thought, the Electrical Research Association undertook a detailed investigation of the matter, in the course of which Churcher, Dannatt, and Dalgleish† measured the contact impedance for a number of electrodes and dielectrics, and also made comparative measurements of permittivity and power factor on various typical materials with electrodes of several types, including mercury, flat metal plates, and graphite applied in the form of Aquadag in the manner introduced by Church and Daynes.‡

The general conclusions reached in this investigation, which was for the most part confined to low frequencies, were as follows. Although contact resistance and capacitance of measurable amounts exist in many cases, yet electrodes of mercury or of graphite backed with metal plates may be used for measurements of permittivity and power factor with satisfactory results. Flat plates alone should not be used. In some cases graphite backed with mercury gives a better contact than that obtained with mercury alone.

Tests made by Hartshorn and Ward at the National Physical Laboratory to various specifications in the course of the last 5 years, in general support these conclusions, and there is no doubt that they form a satisfactory guide for work at power frequencies. When measurements were made at audio frequencies and radio frequencies, however, in certain cases errors were obtained which seemed quite inexplicable on the basis of existing knowledge of electrode contact. Thus whereas Churcher, Dannatt, and Dalgleish estimate that the probable error in ordinary cases will not exceed 10 per cent in power factor, discrepancies of more than 100 per cent were encountered. Also electrodes which appeared to be unsatisfactory at audio frequencies gave good results at radio frequencies, and vice versa. It therefore seemed desirable to pursue the matter further, in the direction of higher frequencies, and the results of experiments made with this object are given in the present paper.

A similar investigation was undertaken independently in the Laboratories of Applied Electricity, Liverpool University, by Sharpe and O'Kane, and as each of these investigations supported the conclusions of the other it was decided to present them together. It will readily be appreciated that in a matter of this kind, depending to some extent on manipulation, the agreement between independent observers each using his own technique is of considerable importance, and although no perfectly general solution of the electrode problem has been found

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† *Journal I.E.E.*, 1926, vol. 64, p. 1152.

‡ *Ibid.*, 1924, vol. 62, pp. 133, 711.

§ *Proceedings of the Physical Society of London*, 1925, vol. 37, p. 215.

† *Journal I.E.E.*, 1929, vol. 67, p. 271; and 1933, vol. 72, p. 252.

‡ *Transactions of the Institution of the Rubber Industry*, 1930, vol. 6, p. 82.

it is believed that the results now presented—in conjunction with those of the E.R.A. investigations previously quoted—will form a fairly complete guide to the limits within which the various forms of electrodes are permissible.

MEASUREMENTS MADE AT LIVERPOOL UNIVERSITY.

Tests were made on two representative samples, namely, ebonite and glass, over a frequency range of 11 000 to 5 million cycles per sec. The types of electrodes used were: (1) Flat brass plates. (2) Aquadag, backed with brass plates. (3) Thin tinfoil, cut to size and fastened to the sample by Aquadag. (4) Thin tin-

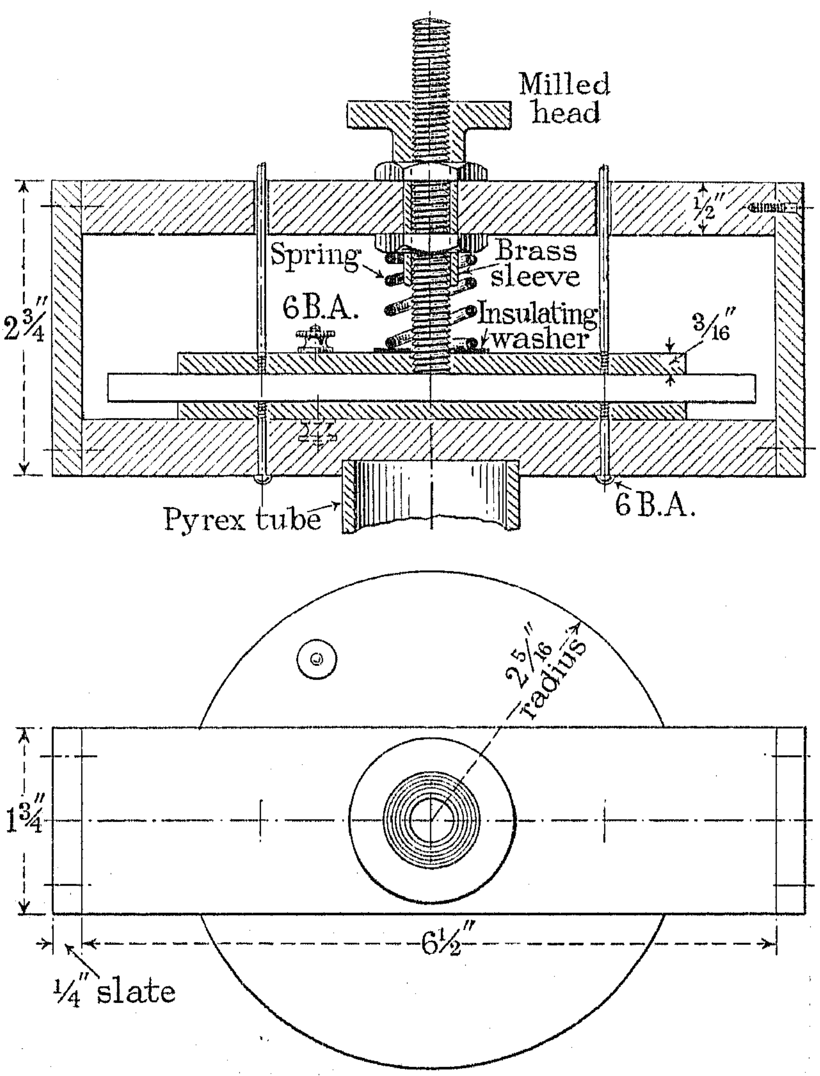


FIG. 1.

foil attached by vaseline (foil thickness = 2 mils). (5) Mercury (ebonite only). (6) The glass sample was silvered on both sides in the same manner as a mirror, and copper-plated over. The electrodes were then marked out and the superfluous coating was scraped away.

The flat-plate electrodes are shown in Fig. 1 and the mercury electrodes in Fig. 2. Owing to the fact that it was proposed to carry out temperature-variation tests, ebonite could not be used for the framework as it would have softened. The cross-pieces were therefore made of wood, well impregnated with shellac, the end pieces being made of slate to avoid leakage. The top plate could be adjusted by means of the milled head, and pressure could be applied to it by means of a steel spring. This apparatus was also used for the other tests, the Aquadag being painted on to the sample over the same area as that of the brass plates. Similarly the tinfoil was cut to size and attached to the sample. The vaseline was smeared over the tinfoil and then wiped away, leaving a very thin film sufficient to attach the foil to the sample.

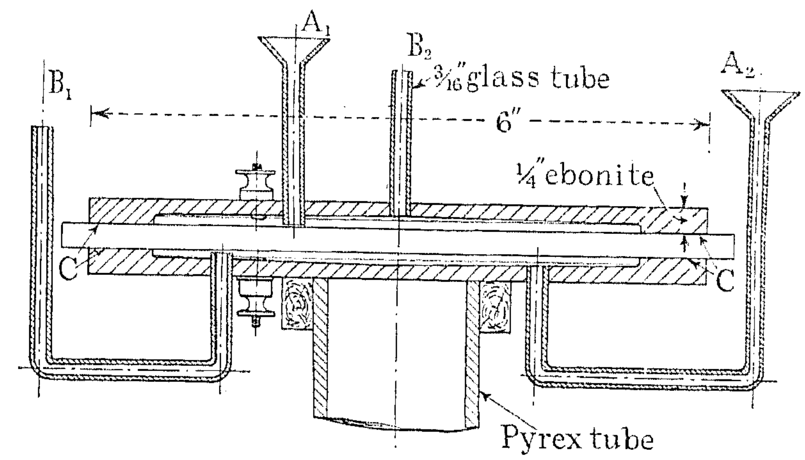


FIG. 2.

The mercury electrodes were constructed of ebonite. The mercury was poured in by way of the glass tubes A_1 A_2, the air escaping through the tubes B_1 B_2. The cavities in the ebonite holding the mercury were slightly domed to facilitate the escape of air. Pressure was applied to the sample by means of a heavy ring resting on the top electrode. Vaseline was smeared on the surfaces C C to prevent the mercury leaking.

The tests were carried out by means of the "substitution in a resonant circuit" method, the circuit

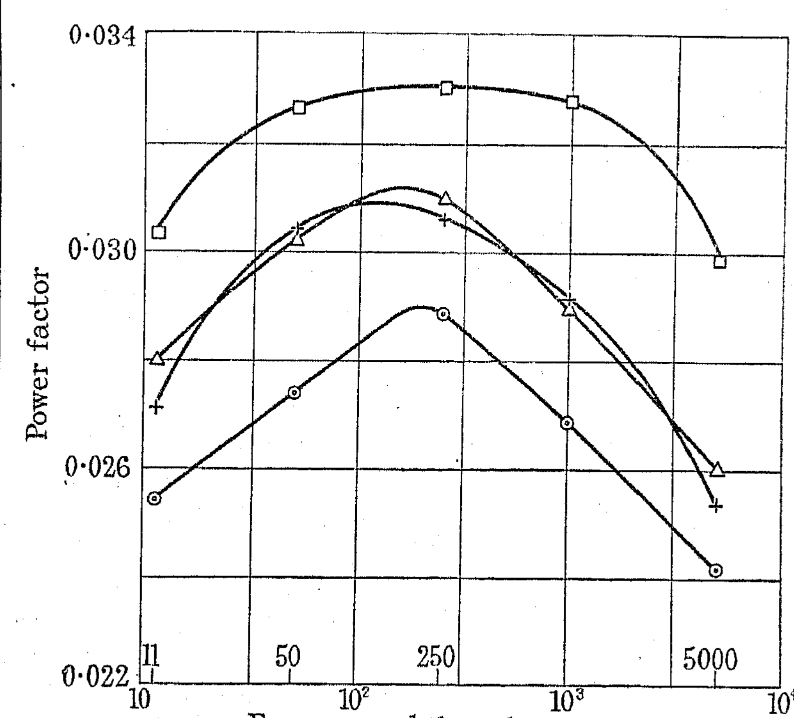


FIG. 3.—Ebonite sample.

⊙ Brass plates. △ Mercury.
+ Tinfoil and vaseline. □ Tinfoil and Aquadag.

being energized by means of a valve oscillator. All the apparatus was shielded as far as possible.

Above 10^6 cycles per sec. it was found that with brass-plate electrodes (see Fig. 1) there was an apparent resistance in the test condenser when the sample was removed. The tests were therefore repeated with the sample out (i.e. as an air condenser), and the necessary correction made.

The complete results are given in Table 1, and, for ease of comparison, are also shown graphically in Figs. 3 and 4. The frequency is plotted to a logarithmic scale. The results obtained with tinfoil and vaseline agree

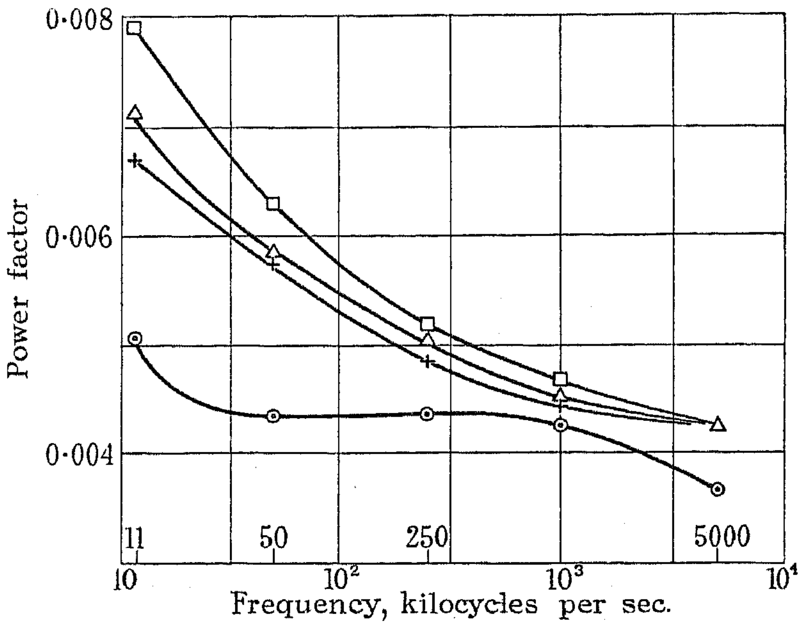


FIG. 4.—Glass sample.

⊙ Brass plates. + Silvering. △ Tinfoil and vaseline. □ Tinfoil and Aquadag.

very closely—probably within the experimental error—with those obtained with silvered electrodes on the glass sample, and mercury electrodes on the ebonite sample, and, since silvering may be expected to give a contact required for mercury electrodes, and it has the advantage of being applicable to samples which are not sufficiently flat to prevent the leakage of mercury.

PRELIMINARY MEASUREMENTS AT THE NATIONAL PHYSICAL LABORATORY.

Table 2 gives the results of measurements made on various occasions at 800 cycles per sec. on samples of ebonite, using several types of electrodes; namely, flat brass plates, the same plates weighted (to the extent of 0·7 lb. per sq. in.) so as to improve the contact, tinfoil stuck to sheet rubber in order to obtain a very flexible electrode which may be pressed into intimate contact with the material, tinfoil stuck to the sample by means of a very thin film of vaseline, and graphite applied in the form of Aquadag and backed with mercury. Samples Nos. 1, 2, and 3, give results in accordance with expectations, i.e. with brass plates there are air films between the sample and the electrodes, the whole of the material is not subjected to the full voltage, and the apparent power factor is too small. Loading the plates tends to flatten the sample, reduce the thickness of the air films, and increase the apparent power factor. Graphite backed with mercury, and tinfoil pressed on to the surface with vaseline as an adhesive, give a very intimate contact. The values obtained with these electrodes are in excellent agreement, and doubtless give the true results. Sample No. 5 is outstanding. The power factor observed with brass plates, instead of being

TABLE 1.

Power Factors.

Sample	Electrodes	Frequency, kilocycles per sec. 11	50	250	1000	5000
Ebonite	Brass plates	0·0254	0·0274	0·0289	0·0269	0·0242
	Aquadag*	0·028	0·0305	0·0363	0·048	0·0415
	Aquadag and tinfoil ..	0·0303	0·0326	0·033	0·0328	0·0299
	Vaseline and tinfoil ..	0·0271	0·0304	0·0306	0·0292	0·0254
	Mercury	0·028	0·0302	0·031	0·029	0·026
Glass	Brass plates	0·00508	0·00435	0·00435	0·00425	0·00366
	Aquadag*	0·0077	0·0071	0·0117	0·0294	0·0885
	Aquadag and tinfoil ..	0·0079	0·0063	0·0052	0·0047	0·00425
	Vaseline and tinfoil ..	0·00712	0·00583	0·00506	0·0045	0·00426
	Silvering	0·0067	0·00575	0·00484	0·00442	0·00425

* The results for Aquadag electrodes are not plotted, as they are too high to be shown on the same scale.

of a most intimate nature, these values are considered to be correct. It is therefore clear that Aquadag backed with brass plates is quite useless as an electrode for high-frequency work. Some improvement is shown when Aquadag is used for attaching tinfoil, but even then the values of power factor are high.

For high-frequency work, therefore, it would seem that tinfoil adhering to the sample by a thin film of vaseline forms a very satisfactory electrode. Its use avoids the necessity of constructing special apparatus, such as is smaller than that obtained with graphite and mercury (believed to be the true value), is more than twice as great. A slight tendency in the same direction is shown by sample No. 4. These results show the danger of assuming, as has sometimes been done, that a high measured power factor necessarily indicates a more perfect contact. They also show the inadequacy of the simple air-gap theory, even for audio-frequency tests.

Some results which are equally illuminating were obtained by measurements on three samples of composite

insulating board. The results are shown in Table 3. The electrodes used were tinfoil on rubber, and graphite in two forms, namely, Aquadag and Leiterit, which is a dry powder used in electroplating. This was used in order to avoid the addition of water to the sample, as in the use of Aquadag. In each case the graphite was backed with the tinfoil on rubber.

TABLE 2.

Results of Measurements of Permittivity and Power Factor on various samples of Ebonite with Various Electrodes, at 800 cycles per sec.

Sample No.	Electrode	Permittivity (observed)	Power factor (observed)
1	Brass plates	2·52	0·0056
	Brass plates, loaded ..	2·60	0·0060
	Tinfoil on rubber ..	2·48	0·0060
	Tinfoil and vaseline ..	3·01	0·0069
	Graphite (Aquadag) and mercury ..	3·02	0·0071
2	Brass plates	2·96	0·0052
	Brass plates, loaded ..	3·06	0·0051
3	Brass plates	1·95	0·0028
	Brass plates, loaded ..	2·25	0·0029
4	Brass plates	2·84	0·0035
	Brass plates, loaded ..	2·85	0·0027
5	Brass plates	2·81	0·027
	Graphite and brass plates	2·98	0·0125
	Graphite and mercury	3·00	0·013

TABLE 3.

Results of Measurements of Permittivity and Power Factor on samples of Composite Board with Various Electrodes, at 1 000 cycles per sec.

Sample No.	Thickness	Electrode	Permittivity (observed)	Power factor (observed)
	mm			
1	7·52	Tinfoil on rubber	5·54	0·0794
		Aquadag ..	5·98	0·0793
		Leiterit	5·96	0·0786
2	1·48	Tinfoil on rubber	3·13	0·0101
		Aquadag ..	3·98	0·0145
		Leiterit	3·16	0·061*
			3·35	0·043*
			3·68	0·031*
3	0·90	Tinfoil on rubber	2·80	0·0114
		Aquadag ..	3·56	0·0144
		Leiterit	2·93	0·0177*
			2·96	0·0173*

* Results obtained in successive measurements.

For the thick sample No. 1, the results obtained with the three electrodes are in good agreement, but for the thinner samples there are important discrepancies. The values of power factor obtained with Aquadag are larger than those obtained with tinfoil on rubber, and subsequent experiments leave little doubt that the values obtained with Aquadag may be regarded as correct. The values obtained with Leiterit on sample No. 2 are thus from 2 to 4 times the true value. These values could not be reproduced with accuracy: the others were all reproducible to 1 or 2 per cent. For sample No. 3 the error in power factor when Leiterit was used was about 20 per cent, and here again the apparent value was too high. It thus appears from a survey of Tables 2 and 3 that imperfect electrode contact may, in conditions met with in practice, give values of power factor in which the error varies from − 20 to + 300 per cent. The very high values of power factor may be given in certain circumstances by either brass plates or graphite. Sample No. 2 of Table 2 differed from most of the others in having a rather rough surface, which suggested that the high values depend in some way on the roughness of the surface. It was therefore decided to make systematic measurements at both audio and radio frequencies on plate glass, which was chosen as a homogeneous material having a very smooth surface, and mycalex, which has a somewhat rougher surface.

DETAILED MEASUREMENTS AT THE NATIONAL PHYSICAL LABORATORY.

For testing purposes, measurements of permittivity and power factor of sheet materials are usually made at frequencies of 1 000 (or 800) and 1 million cycles per sec. The audio frequency is used because at this frequency the measurement is most easily made, and the properties at this frequency are, in general, a useful guide to those at other frequencies. The measurement at radio frequency is made when it is considered of importance to obtain data under working conditions. The present series of measurements were therefore made at these two frequencies. All the measurements were made by means of a Schering bridge; as the use of this bridge at audio and radio frequencies has already been described,* it is sufficient to state here that a substitution method was employed, the reference standard being a variable air condenser of known power factor; the bridge components and the electrodes were all screened, a Wagner earth-connection was used, and in conjunction with this a guard ring was applied to the sample in every case so as to eliminate any effects due to surface leakage round the outer edges. Under these conditions measurements on a given sample with given electrodes could be repeated with an accuracy of better than 1 per cent.

As the nature of the electrodes is the most important variable, they will be specified in detail. They were:—

(1) *Tinfoil stuck to the sample by a very thin film of vaseline.*—The foil was very carefully pressed into contact with the sample over the whole electrode-area with the ball of the thumb, and when this operation had been satisfactorily completed the foil presented an almost mirror-like surface. Thin foil is necessary in order to get close adhesion, but at the same time it should not be so thin as to tear during the application, or to possess considerable resistance, which would have

* *Journal I.E.E.*, 1933, vol. 72, p. 169.

important effects at radio frequencies. A thickness of about 0·01 mm was used. On one side of the sample the electrode took the form of a circle of diameter 10 cm separated by a gap of 1 cm from a guard ring of radial width 1·5 cm. The gap between the main electrode and the guard ring was made as wide as 1 cm so that surface-resistivity measurements could be made with the same arrangement.

(2) *Mercury contained in cast-iron clamps.**—The lower electrode was 22 cm diameter, the upper electrode 18 cm, while the gap between electrode and guard ring was of radial width 2 mm.

(3) *Brass plates of the same radial dimensions as the tinfoil, and of thickness* 5 *mm.*—The surfaces in contact with the sample were ground flat and were held in contact by the weight (0·06 lb. per sq. in.) of the electrodes alone.

(4) *Graphite applied in the form of Aquadag.*—The dimensions were as for tinfoil. The aquadag was diluted with distilled water to the consistency of ordinary drawing-ink, and the circular outlines of the electrodes were then drawn on the sample by means of ink-compasses, the complete electrode-surfaces being painted

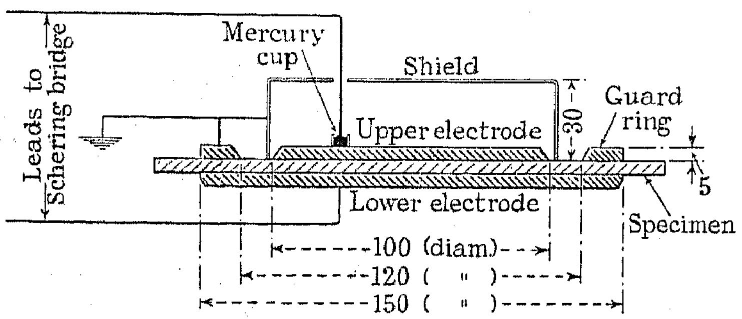


FIG. 5.—Shielded brass-plate electrodes, for use with Aquadag or tinfoil or alone, at audio and radio frequencies. (All dimensions in millimetres.)

over afterwards with a pencil-brush. The sample was then allowed to dry for several hours.

Contact with the graphite was made by the application of the brass plates of the same area. For certain experiments contact was made with the graphite by covering it with mercury of the same area as in (2), or the application of tinfoil with vaseline as in (1). These arrangements will be referred to as Aquadag-brass, Aquadag-mercury, and Aquadag-tinfoil respectively.

The mercury electrodes were screened by the outer casing of the clamps. The other electrodes were screened by means of a hollow brass cylinder of 10·2 cm inside diameter, 3 cm long, and closed at the upper end, which stood on the surface of the sample so as to enclose the central electrode (Fig. 5). This cylinder was made so as to touch the surface of the sample at three points only (small projections being made on its lower rim for this purpose), so that it had practically no effect on the action of the guard ring, to which it was connected. The lead to the central electrode passed through a small hole in the top of the shield to a mercury cup on the electrode, and disconnection of the specimen from the bridge was effected by the removal of the lead from this mercury cup without removing it from the shield. With this arrangement, capacitance between the electrodes and the various bridge components, such as the shield of the standard air condenser, does not affect the results.

* *Journal I.E.E.*, 1934, vol. 74, p. 179.

The measurements were made under approximately constant atmospheric conditions, the temperature being 20° C. and the relative humidity 55 per cent. The results are given in Tables 4 and 5. The measurements

TABLE 4.

Results of Permittivity (κ) *and Power Factor* (*P.F.*) *Measurements on Plate Glass at Audio and Radio Frequencies, using Various Electrodes. Thickness of sample,* 4·3 *mm.*

Electrode	Frequency, 1 000 cycles per sec.		Frequency, 10^6 cycles per sec.	
	κ	P.F	κ	P.F.
Tinfoil	10·20	0·0268	9·40	0·0096
Mercury	10·14	0·0256	9·52	0·0096
Brass plates	8·80	0·0213	8·72	0·0086
Aquadag-brass	10·33	0·0262	9·46	0·044
Aquadag-mercury	10·22	0·0264	9·62	0·0101
Aquadag-tinfoil	10·38	0·0256	9·62	0·0094

on glass may be readily explained. At a frequency of 1 000 cycles per sec., the results obtained with tinfoil, mercury, and graphite, backed with brass plates, tinfoil, or mercury, are practically the same. The differences may well be due to differences of temperature. Brass

TABLE 5.

Results of Measurements of Permittivity (κ) *and Power Factor* (*P.F.*) *of samples of Mycalex, using Various Electrodes.*

Sample	Electrode	Frequency, 800 cycles per sec.		Frequency, 10^6 cycles per sec.	
		κ	P.F.	κ	P.F.
A	Aquadag-mercury	6·26	0·0023	5·9	0·0025
	Aquadag-tinfoil	6·3	0·013	5·9	0·0021
B	Aquadag-mercury			6·3	0·0020
	Aquadag-tinfoil			6·2	0·0029
C	Aquadag-mercury	6·52	0·0039	6·46	0·0021
	Aquadag-tinfoil	6·57	0·0058	6·61	0·0021
D	Aquadag-mercury	6·21	0·0057	6·13	0·0020
	Aquadag-tinfoil	6·30	0·0058 0·0072*	6·25	0·0021
	Aquadag-brass	6·3	0·0062		
E	Aquadag-mercury	8·75	0·0028		
	Aquadag-tinfoil	8·6	0·0028		

* Value obtained after removing and replacing tinfoil.

plates alone give results which are low by about 15 per cent, and a simple calculation shows that these may be completely accounted for by an air film, between each electrode and the sample, of a thickness equal to about 1 per cent of that of the glass, i.e. about 0·04 mm. At a frequency of 10^6 cycles per sec., the brass plates give results which are low by 10 per cent, and these

also may be explained by the air films, although on this occasion they were evidently rather thinner (0·03 mm). Graphite backed with brass gives a power factor which is at least 4 times the true value; while tinfoil, mercury, and graphite backed with these materials, give practically the same result.

Turning now to the results for mycalex (Table 5), we observe that graphite backed with tinfoil frequently gives values of power factor which are much too high at a frequency of 800 cycles per sec., although at 10^6 cycles per sec. the same electrodes give the true result (samples A, D, and C). This is the reverse of the effects shown by Aquadag-brass electrodes on glass (Table 4). We have therefore to account for the fact that with some materials Aquadag electrodes give correct values of power factor at audio frequencies, and very high values at radio frequencies, while with others they give correct results at radio frequencies and very high values at audio frequencies. It is a striking fact that in all such cases the value obtained for the permittivity is always practically correct.

Theoretical Discussion.

Fig. 6 shows diagrammatically on a large scale a section of part of the surface of an insulating material. There is an outer layer A of material of high conductivity (tinfoil, brass, or mercury), which serves as one terminal of the test condenser, and may be regarded as an equipotential surface. Owing to irregularities in the surface of the material, the layer A makes actual contact at a few points only, and there is a space between A and the surface of the material which may be partly filled in with graphite (shown in black). Passing from A along the lines of electric force which penetrate the dielectric, let the dotted line B represent the first equipotential surface lying wholly in the dielectric. Near the opposite surface of the material there will be similar equipotential surfaces B_1 and A_1. We wish to measure the capacitance and power factor of the current path between B and B_1, but we can only measure that between A and A_1. The current paths AB and B_1A_1 may be very complicated, and will vary considerably with frequency, but at any one frequency they may be represented by a condenser of capacitance C_1 and loss angle δ_1. This condenser must be regarded as connected in series with one of capacitance C_2 and loss angle δ_2, representing the material under test; the capacitance C and loss angle δ measured are those of this series combination. The equations for the capacitance and loss angle of these condensers in series may be written in the form

In all practical cases the film capacitance C_1 will be very large compared with the true capacitance C_2 of the sample. Thus equation (1) may be written, with sufficient approximation, in the form

$$C = C_2\left(1 - \frac{C_2}{C_1}\right)\frac{\left[1 + \tan^2\delta_1 + \frac{C_2}{C_1}\tan^2\delta_2\right]}{1 + \left(\tan\delta_1 + \frac{C_2}{C_1}\tan\delta_2\right)^2} \quad . \quad (3)$$

Equations (2) and (3) represent the relations between the apparent capacitance (C) and power factor ($\tan\delta$) and the true values (C_2 and $\tan\delta_2$), and it is evident that the terms in brackets contain the errors due to the electrodes. It is now not difficult to see that in certain circumstances the error in the power-factor value may be very large. Consider, for example, a material of true power factor 0·0025, with Aquadag-tinfoil electrodes. The ratio of the true capacitance to the film capacitance (C_2/C_1) is not known, and it will obviously

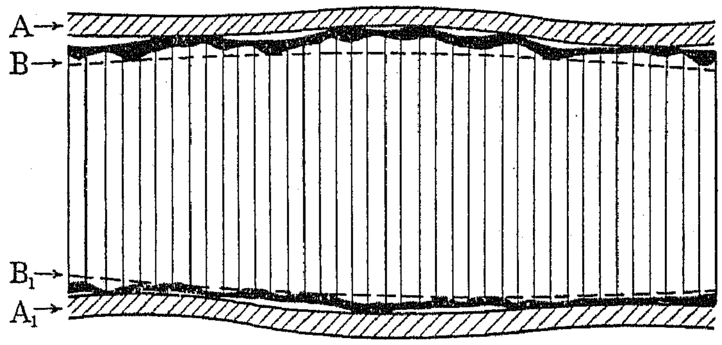


Fig. 6.

depend on the roughness of the surface, but with a sample of thickness 3 mm, say, a ratio of 1 per cent may be considered probable. The value of $\tan\delta_1$ is also unknown, but it is evident that, since the condenser C_1 includes graphite and vaseline, a value of 0·2 is not out of the question. Substituting these values in equation (2), we find that $\tan\delta = 1{\cdot}8\tan\delta_2$, i.e. the error in the power factor is 80 per cent. Substitution in (3) shows that the error in capacitance is only 1 per cent in this case. The errors in such cases are almost entirely due to the term $\frac{C_2}{C_1}\cdot\frac{\tan\delta_1}{\tan\delta_2}$ in the expression for power factor. If, for example, $\tan\delta_1$ had the value unity in the above case, the apparent power factor would be 3 times as large as the true value, and the error in capacitance would still be only 1 per cent. This is evidently the explanation of the high values of power

$$C = \frac{C_2C_1}{C_2 + C_1}\,\frac{\left[1 + \frac{C_1}{C_1 + C_2}\tan^2\delta_1 + \frac{C_2}{C_1 + C_2}\tan^2\delta_2\right]}{\left[1 + \left(\frac{C_1}{C_1 + C_2}\tan\delta_1 + \frac{C_2}{C_1 + C_2}\tan\delta_2\right)^2\right]} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

$$\tan\delta = \tan\delta_2\,\frac{\left[1 + \tan^2\delta_1 + \frac{C_2}{C_1}\left(\frac{\tan\delta_1}{\tan\delta_2} + \tan\delta_1\tan\delta_2\right)\right]}{\left[1 + \frac{C_2}{C_1} + \tan^2\delta_1 + \frac{C_2}{C_1}\tan^2\delta_2\right]} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

factor recorded above. The values assumed would, for example, explain the result at 800 cycles per sec. on sample A (Table 5).

In general, it may be seen that the error in the value of power factor is zero when $\tan \delta_1 = \tan \delta_2$, but that whenever the power factor of the electrode film exceeds that of the material under test ($\tan \delta_1 > \tan \delta_2$) the measured power factor is too high. The maximum error occurs when $\tan \delta_1$ is approximately equal to unity, and the error in $\tan \delta$ is then approximately $\frac{1}{2} C_2/C_1$. Since this is an absolute, and not a fractional, error, it may become very serious when measurements are made on materials of low power factor. If $\tan \delta_1$ is increased beyond the value unity (phase angle 45°) the error diminishes, becoming zero again as $\tan \delta_1$ approaches infinity, which is, of course, its value when the contact is perfect.

It is possible for the value of $\tan \delta_1$ to become equal to unity in a case like that of Fig. 5 at either high or low frequencies. For the current path from A to B may evidently be represented by a number of elementary paths in parallel. Some of these will be pure conductances, others pure capacitances, and others capacitances in series with resistances. The power factor of the combination will thus contain terms of the form $G/(C\omega)$ and $RC\omega$. The first of these tend to become large at low frequencies and the second at high frequencies, and we therefore have the possibility of very large errors in either case. Examples of these are contained in the results already given. Such errors are, in general, only likely to occur when graphite is used, but they may also occur with samples showing large surface leakage used with brass plates alone, especially if the surface is rough and the samples not flat. Sample No. 5, Table 2, is an example of this.

When $\tan \delta_1$ is less than $\tan \delta_2$, which will usually be the case when brass plates alone are used, or when tinfoil is applied with vaseline, the measured power factor is too small, but the maximum fractional error in this case is C_2/C_1, which is never likely to be very serious, although it is not often negligible.

It will be observed that the errors in the value of the capacitance are seldom of any consequence. The fractional error is usually of the order C_2/C_1. The only case in which very serious errors arise is that in which $\tan \delta_2$ becomes large, i.e. the power factor of the sample to be measured is very large. In such a case, if $\tan \delta_1$ is small, the capacitance measured tends to approach C_1 instead of C_2, but as such conditions are seldom encountered in dielectric testing they need not be considered further.

Conclusions.

The conclusions reached by the authors, as a result of these and similar measurements, may be summarized as follows:

(1) The mercury electrode is probably the one which is most satisfactory for general use at all frequencies. It is of low resistance and thus forms a true equipotential surface which follows closely the irregularities in the surface of the specimen. The capacitance of the contact film (C_1) is thus always very high, and the term C_2/C_1, which is a factor in all the errors, is always small. The chief disadvantage of mercury is the difficulty of its manipulation. It is usually necessary to construct special apparatus to deal with samples of any particular form (see, for example, the paper by T. Iorwerth Jones already referred to*), and variations in the thickness of the sample are apt to make the use of mercury impossible.

(2) Graphite (applied as Aquadag) backed with mercury probably gives slightly better contact than mercury alone, as was suggested by Churcher, Dannatt, and Dalgleish. The difference, judged by its effect on permittivity and power-factor measurements, is, however, very small, and the additional complication would seldom be worth while. Provided, however, that a mercury backing is used, the graphite contact appears to give a slight advantage even up to a frequency of 1 million cycles per sec.

(3) When the use of mercury is impracticable, the most generally satisfactory form of electrode for alternating-current work is thin tinfoil very carefully applied with a minimum quantity of vaseline as an adhesive, and backed with thick metal plates for high-frequency work. The only disadvantage of this form of electrode is that its application is a rather lengthy operation which must be performed for each sample.

(4) Graphite in the form of Aquadag, with metal plates for making contact, is an electrode which is very simple to apply. It is very satisfactory for direct-current work, and for alternating-current work at low frequencies in most cases, but at high frequencies, and in certain cases at low frequencies, it gives values of power factor which are too high. For alternating-current work the metal backing-plates should be of the same area as the graphite, and it is advisable to apply pressure to these plates and to note any apparent change of power factor produced. This change will give an idea of the probable error due to the nature of the contact. This form of electrode is most satisfactory on surfaces which are smooth and flat, but it should not be used at radio frequencies. Graphite applied as a dry powder (Leiterit) is less satisfactory than Aquadag.

(5) Flat metal plates are, in general, unsatisfactory as electrodes, but they may be used for samples which are thick ($\frac{1}{4}$ in. or more) and flat. The errors caused by their use are, as a rule, smaller than those due to graphite at radio frequencies. These errors are usually of the opposite sign to those due to graphite, and measurements made with metal plates before and after the application of graphite are therefore sometimes useful in fixing limits of error. Samples showing very pronounced surface-leakage effects may give very high values of power factor, even with brass plates.

The work at Liverpool University was carried out under the direction of Prof. E. W. Marchant, D.Sc., Past-President, and the authors wish to thank him for his interest in the work and the valuable advice which he has given. Acknowledgment is also due to the Department of Scientific and Industrial Research for grants which have enabled this portion of the work to be completed.

* *Journal I.E.E.*, 1934, vol. 74, p. 179.

THE HEATING OF CABLES EXPOSED TO THE SUN IN RACKS.*

By E. B. WEDMORE, Member.

[REPORT (REF. F/T79) OF THE BRITISH ELECTRICAL AND ALLIED INDUSTRIES RESEARCH ASSOCIATION.]

(*Paper first received* 19*th January, and in final form* 8*th February*, 1934.)

SUMMARY.

In general, the temperature-rise of the surface of a cable, freely exposed to the air, due to the current carried, will only be a few degrees above ambient temperature, whereas if the cable is exposed to direct sunlight a substantial increase of temperature will occur. This increase may be treated as additional to that due to the load, provided it is noted, in calculating the former, that the resistance will be increased at the higher temperature reached by exposure to the sun.

It is found that this rise is brought about in part by radiation, but mainly by convection. It therefore varies with the intensity of the solar radiation, the velocity of the ambient air, the diameter of the cable, its location (i.e. the extent to which it is exposed), and the nature of the surface of the cable.

The maximum solar radiation in different parts of the world is known approximately, and some tabular information is given in the paper. From this the temperature-rise of a cable of given diameter can be determined for a given air velocity by means of a factor F varying with the diameter of the cable and with the air velocity. It is found, further, that there is in practice an approximate minimum air velocity, and the maximum rise is tabulated for this figure.

This maximum will be attained in about half an hour, and will be reached if the sky is clear and the cable is directly exposed normal to the sun's radiation between, say, 12 noon and 2 p.m. Summer Time.

Under these conditions cables of 2 to $2\frac{1}{2}$ in. diameter, in this country, may show a temperature-rise of 17 deg. C. This figure must be deducted from the permissible rise of, say, 50 deg. C. above shade temperature, thus materially reducing the rating of the cable.

The data given are based on results obtained in London, Milan, and Buenos Aires, and are in good agreement.

An account is given of the methods employed and results obtained, together with supplementary information on certain technical features that presented difficulty during the investigation.

CONTENTS.

CONTENTS—*continued*.

(1) OBJECT OF THE INVESTIGATION.

The object of the investigation was to ascertain the relationship between the direct radiation of the sun, and consequent heating of conductors exposed to it.

(2) NATURE OF TESTS.

Table 1 gives the details and disposition of the cables used during the investigation.

Instruments Used during Tests.

Numerous readings were taken during the sunny periods of the day on all thermometers, namely: (i) Solar-radiation thermometers of the maximum type. (ii) Shade-temperature thermometers fitted in louvred boxes. (iii) Cable-sheath thermometers.

Tests at West Kensington.

Two thermometers were used, attached to the sheath of the cable on the sunny and shady sides respectively.

Tests at Buenos Aires.

Three thermometers were attached to the sheath of the cable; two on the sunny side, one with its stem shielded to prevent absorption of the sun's rays; the third thermometer was fixed on the shady side.

Tests at Milan.

Cable-sheath temperatures were taken by means of thermocouples embedded in the lead, in contact with the armouring, or immersed in the jute.

(3) CORRELATION OF OBSERVATIONS.

The difference between the reading of a solar-radiation thermometer exposed to the sun, and the shade temperature of the air, gives a measure of the maximum effect of exposure to the sun's radiation at the particular locality concerned. The temperature-rise of the cable

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

TABLE 1.

Disposition of Cables.

Locality	Cable		
	Description	Diameter (cm)	Disposition
Milan, Italy.. ..	Telephone cables all bare, lead-covered	2·1 4·2 7·2 5·4	Suspended along terrace of laboratory, east to west, above an asphalt pavement
	Armoured cable, jute served ..	6·7 6·0 4·8 4·5	Suspended along terrace of laboratory, east to west, above an asphalt pavement. (See Figs. 1, 2, 3, and 4)
	Braided	3·7	
Buenos Aires, South America	Armoured cable, 20 000 volts, double taped and compounded	8·9	Mounted on rack against south wall of railway cutting. Lowest cable but one of twenty. Clearance between cable and wall $1\frac{1}{2}$ in. (See Fig. 5)
West Kensington, London, England	Bare lead-covered, 11 000-volt, paper-insulated feeder cable	7·3 6·7	Supported against wall in racks along north side of railway cutting, running east to west. Second and fifth from lowest of seven respectively
	Bare lead-covered, 11 000-volt, paper-insulated feeder cable	6·7	Ditto on south side. Fifth from lowest of eight. (See Fig. 6)

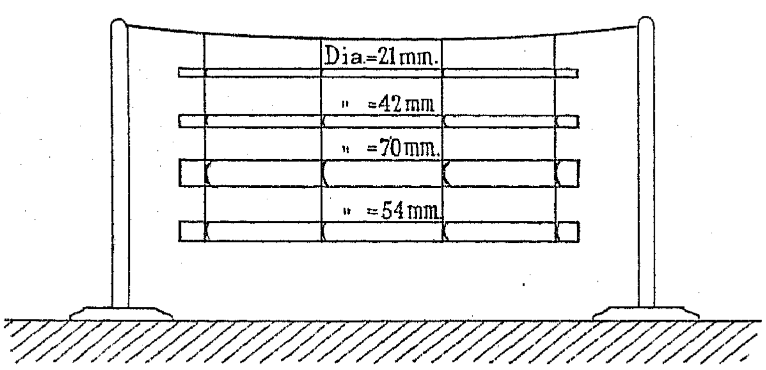


FIG. 1.—Cables suspended along terrace, east to west, above asphalt pavement.

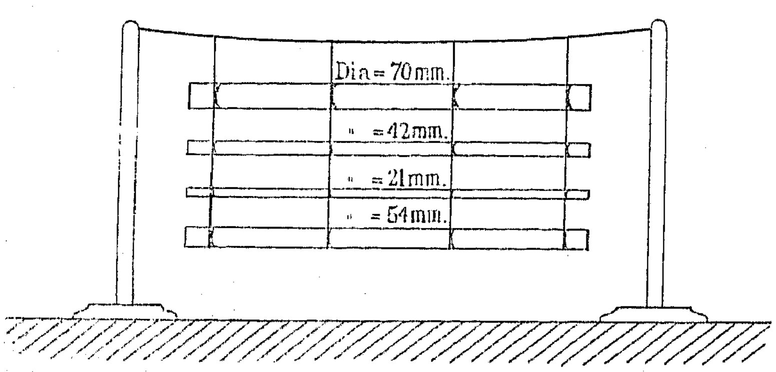


FIG. 2.—Cables suspended along terrace, east to west, above asphalt pavement.

cover obtained by the mean of temperature-rises observed on the sunny and shady sides of the cable, when subject to the sun's radiation, is a fraction of the sun's radiation, and the main purpose of the investigation was to establish the value of this fraction for various sizes of cables for the severest conditions likely to be encountered in practice. This fraction will be referred to as factor F.

This factor F applied to the maximum excess reading on the solar-radiation thermometer at a given locality

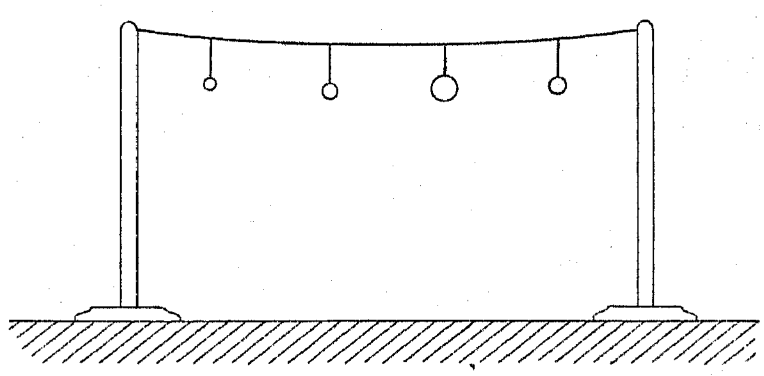


FIG. 3.—Cables suspended along terrace, east to west, above asphalt pavement.

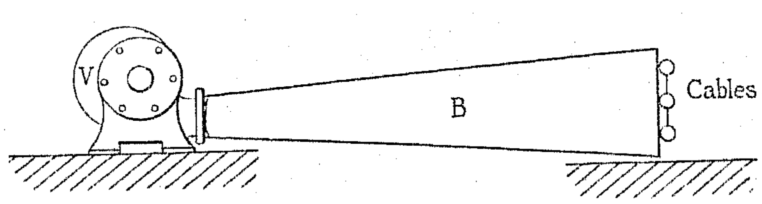


FIG. 4.—Cables under wind test.

gives the maximum temperature-rise of the cable above shade temperature.

When the experimental observations are investigated, local conditions and any other factors likely to invalidate the results of direct comparison should be given

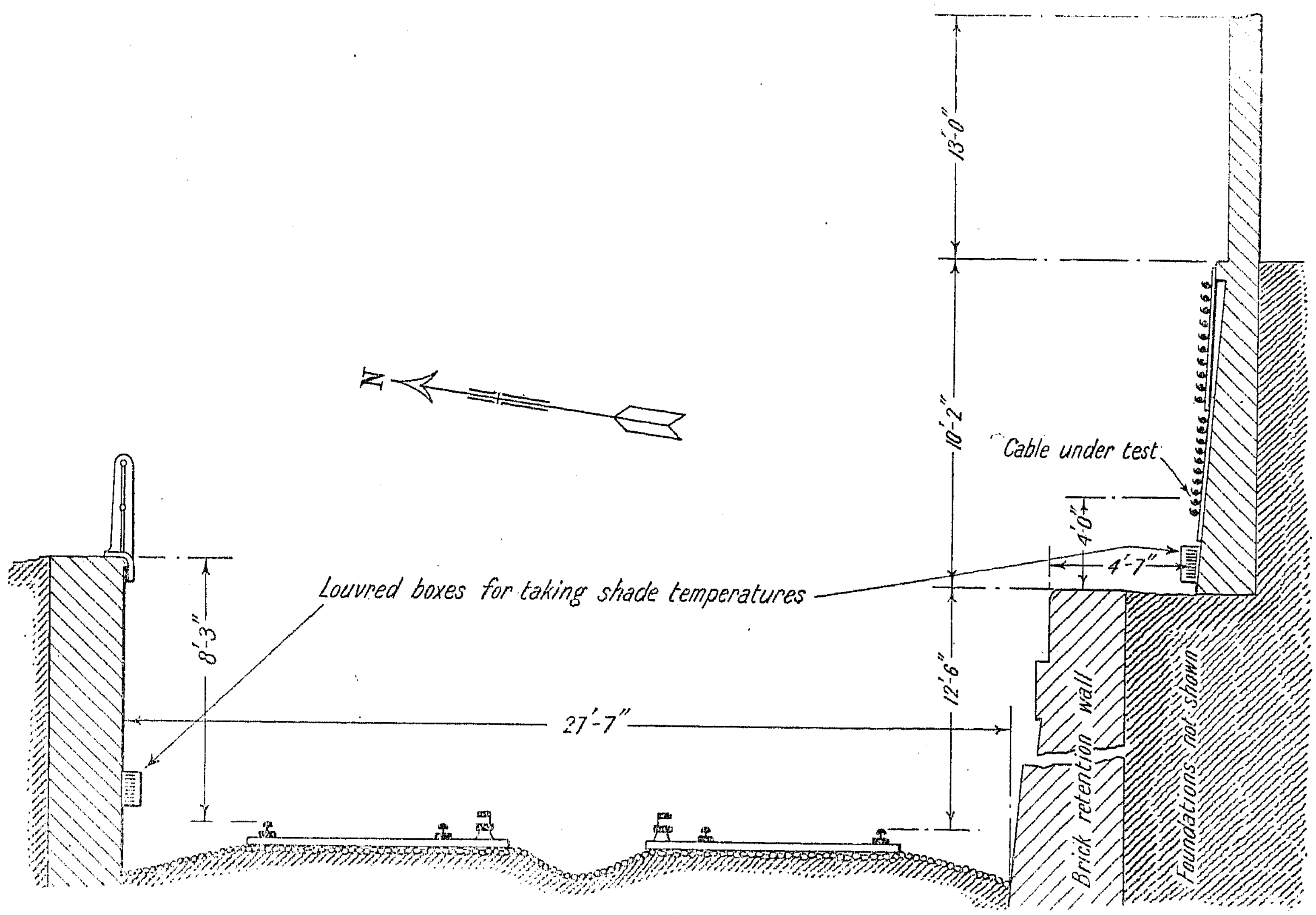


FIG. 5.—Section of cutting.

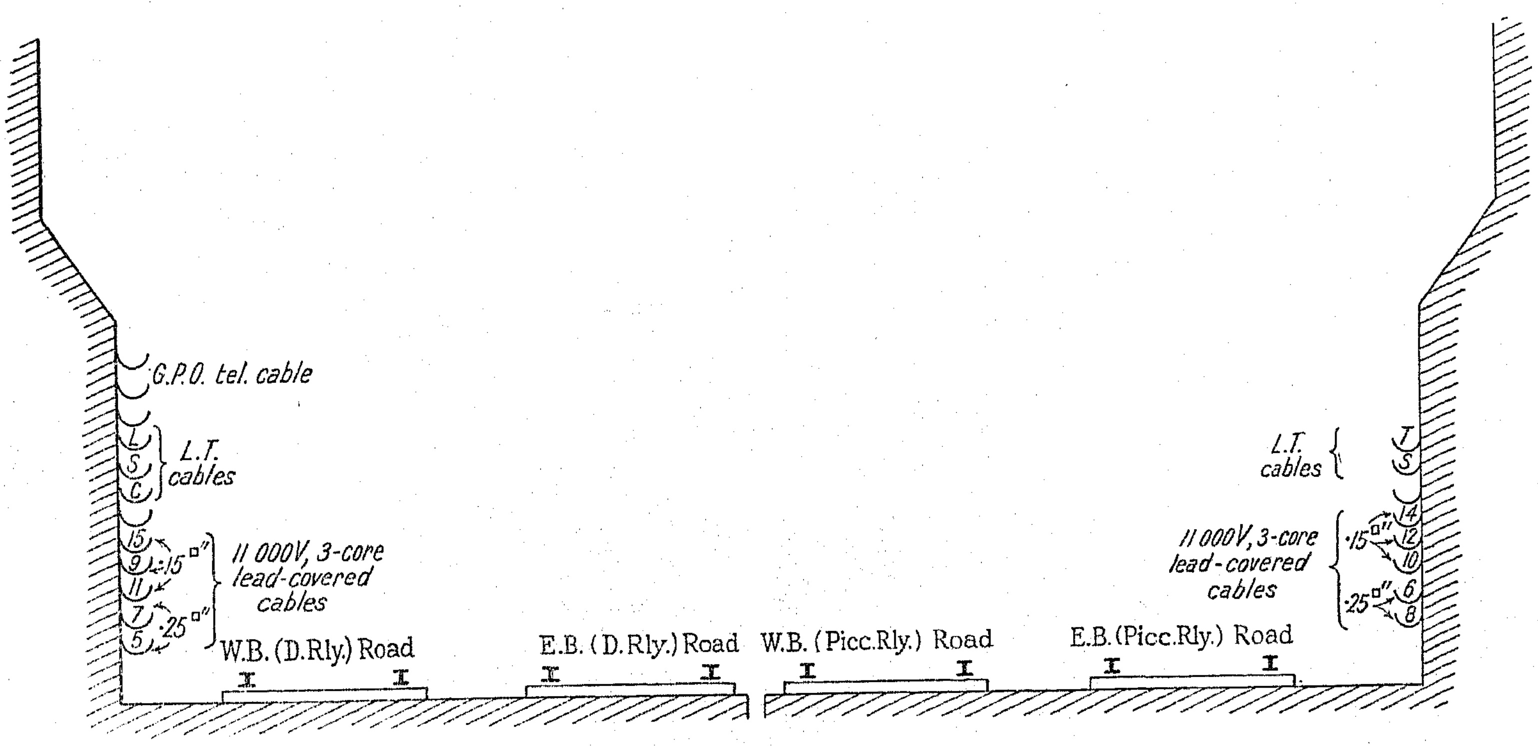


FIG. 6.—Section of cutting 100 yards west of Barons Court station, showing positions of cables on retaining walls.

careful consideration. Those of importance are therefore detailed in Appendices I, II, and III.

The solar-radiation thermometer on which the readings taken in London are based has an efficiency of within 95 per cent of a perfect instrument, and the thermometer used in Italy has been compared with it under identical conditions. Tests show that the two thermometers approximate closely.

No direct comparison has been made with the instruments used in Buenos Aires, but as two thermometers were always used and the greatest difference between them was approximately 2 deg. C., it has been assumed that the instrument giving the higher reading is the better and probably equal in efficiency to the London instrument.

TABLE 2.

Solar-Radiation Thermometers.

Locality	Mounting and relative position	Correction to reduce observations to standard
West Kensington	Mounted horizontally on a vertical deal board on a wall on one side of a deep railway cutting about 6 ft. from ground. This mounting is taken as standard. (See Fig. 7)	Nil
Milan	Mounted horizontally on a wooden stool about 2 ft. from level of ground, and 7 ft. from other surrounding objects	Nil
Buenos Aires	Two solar-radiation thermometers were fixed in clips on the cable, which was one of several situated on the south wall of a double-track railway cutting. In addition to these, a few readings were taken with a solar indication thermometer fixed at right angles to the wall, (*a*) below the cables and (*b*) above the cables, and also with the thermometer mounted horizontally at the top of two wooden stakes 3 ft. from the wall and 2 ft. 3 in. from the level of the ledge. (See Fig. 8)	Subtract $7\frac{1}{2}$ per cent of rise above air temperature

(4) EFFECT OF SHIELDING THE STEM OF A MERCURY THERMOMETER.

At Buenos Aires the effect of shielding the stem of a mercury thermometer from the sun's rays was tried, the thermometer being attached to the sunny side of the cable. The readings on the hooded thermometer were found generally to be about 3 per cent less than on the adjacent thermometer without a hood.

In the summary of results (Table 3) the readings of the unshielded thermometer have been used; therefore any error involved is on the safe side.

The mounting and relative position of the solar-radiation thermometers, together with the estimated correction required to reduce the readings to standard conditions, are given in Table 2. The standard conditions are taken as being equivalent to those employed at West Kensington.

(5) CORRECTIONS FOR WIND VELOCITY.

Tests carried out in Italy show that the rise in temperature of the cable cover is influenced by wind velocity. Test conditions were varied, therefore, by subjecting the cables to winds of various speeds. The wind was obtained from a fan controlled by ordinary methods and was measured by a windmill-type anemometer.

Tests corresponding to a wind speed equal to zero were carried out in the laboratory on cables suspended in still air, the temperatures being measured by thermocouples and the speed of the wind by means of a windmill-type anemometer.

It can be shown that the mean rise of temperature of the cable cover, and consequently the factor F, should be, according to the generally accepted theory of forced convection, expressible as a function of the ratio (Cable diameter)/(Velocity of wind) for a moderate range of velocities and diameters.

The results of the series of experiments carried out in Italy can be expressed by the following equations to a sufficient degree of accuracy.

Bare Lead-Covered Cables (Fig. 9):—

$$\begin{aligned} \text{Diameter } (d) &= 2\cdot 1\text{–}7\cdot 0 \text{ cm.} \\ \text{Velocity } (v) &= 1\text{–}2\cdot 25 \text{ m.p.h.} \\ &= 44\text{–}110 \text{ cm per sec.} \\ F &= 0\cdot 25\sqrt{(d/v)} - 0\cdot 025(d/v) \end{aligned}$$

Armoured Cables (Fig. 10):—

$$\begin{aligned} \text{Diameter } (d) &= 4\cdot 8\text{–}6\cdot 7 \text{ cm.} \\ \text{Velocity } (v) &= 1\text{–}2\cdot 5 \text{ m.p.h.} \\ &= 44\text{–}130 \text{ cm per sec.} \\ F &= 0\cdot 58\sqrt{(d/v)} - 0\cdot 11(d/v) \end{aligned}$$

For armoured cable the calculation of factor F is based on the mean cable temperature, i.e. the value obtained after correcting the recorded observation on the sunny side to reduce it to standard.

At Buenos Aires, records of wind velocity were made at the time that cable-temperature observations were being taken. It is doubtful, however, whether these

wind velocities correspond to the movements of the wind round the cables. On making a correction to factor F for a wind velocity of 4–5 m.p.h. these results are more in agreement with the Italian results.

No observations of wind velocities were made at West Kensington, but the records indicate still air, and it may be assumed that the movement of air in this case was practically equivalent to the limiting condition of 1 m.p.h.

(6) Summary of Results.

The summary of results (Table 3) has been corrected in accordance with the explanations given above and in Appendices I, II, and III, taking West Kensington as standard with a wind velocity of 1 m.p.h.

The only British results considered are those where the temperature-rise of the cable exceeded 10 deg. C. This corresponds to continuous sunshine and a clear sky, as experienced at West Kensington.

In the case of the Italian observations there was no appreciable difference of temperature between the sunny and shady sides of the lead-covered cable. The temperature on the sunny side is therefore used as the mean. For armoured cable, differences between the two sides were found, but as no actual values for the shady side were recorded the mean values given in the tables have been obtained by taking an average of the difference between the sunny- and shady-side temperatures for Buenos Aires and subtracting this figure from the sunny-side temperature of the cable tested at Milan.

A study of the figures for armoured cable tested at Buenos Aires shows that the correction will amount to from 4 to 5 deg. C., depending on the diameter of the cable and the actual recorded temperature of the sunny side.

Wind-velocity corrections for Buenos Aires assume that the wind velocity round the cable is half the recorded velocity. Where no record was made, probably because the wind velocity was less than 5 m.p.h. (the minimum recorded), an assumed wind velocity round the cables of 2 m.p.h. has been adopted.

Figs. 9 and 10 embody the results given in Table 3. These show the value of the factor F for various sizes ot lead-covered and armoured cables.

Table 3.

Summary of Results.

Diameter of cable (cm)	Kind of cable,* and locality	Maximum rise of solar-radiation thermometer (deg. C.)		Wind velocity (m.p.h.)	Cable temperature (° C.)			Factor of cable cover, $F(=B/A)$	
		Actual	Corrected (A)		Sunny side	Shady side	Mean (B)	Uncorrected	Corrected for wind velocity
2·1	A, Milan	30	30	1	11	—	11	0·37	0·37
4·2		30	30	1	15	—	15	0·5	0·5
5·4		30	30	1	17	—	17	0·57	0·57
7·0		30	30	1	18·5	—	18·5	0·62	0·62
6·7	A, W. Kensington	22·75	22·75	—	14	10	12	0·53	0·53
6·7		21·75	21·75	—	12·5	10·5	11·5	0·53	0·53
6·7		21·5	21·5	—	11·5	10·5	11	0·51	0·51
6·7		22·5	22·5	—	15	12	13·5	0·60	0·60
6·7		36	36	—	22·5	17·5	20	0·56	0·56
6·7		34	34	—	19·5	18·5	19	0·56	0·56
4·8	B, Milan	30	30	1	24	—	21·3	0·71	0·71
6·0		30	30	1	28	—	25·3	0·84	0·84
6·7		30	30	1	29	—	26·3	0·88	0·88
8·9	C, Buenos Aires	30·5	28·0	—	14	9	11·5	0·41	—
8·9		30·25	28·0	—	16·25	11·75	14	0·50	—
8·9		29	27	13	14	10·8	12·4	0·46	0·60
8·9		28·2	26	<5	14·8	10·0	12·4	0·48	0·60
8·9		28·4	26·5	5	13	7·8	10·4	0·39	0·51
8·9		28·6	26·7	11	14·3	7·8	11·1	0·41	0·53
8·9		29·2	27·3	<5	16	10·2	13·1	0·48	0·60
8·9		28·2	26·4	<5	15·6	9·2	12·4	0·47	0·59

* A = bare lead-covered; B = armoured, jute-served; C = armoured.

Bare Lead-Covered Cables (2 to 7 cm diameter).

The results given in Fig. 10 justify the assumption that the tests at West Kensington and Milan are suffi-

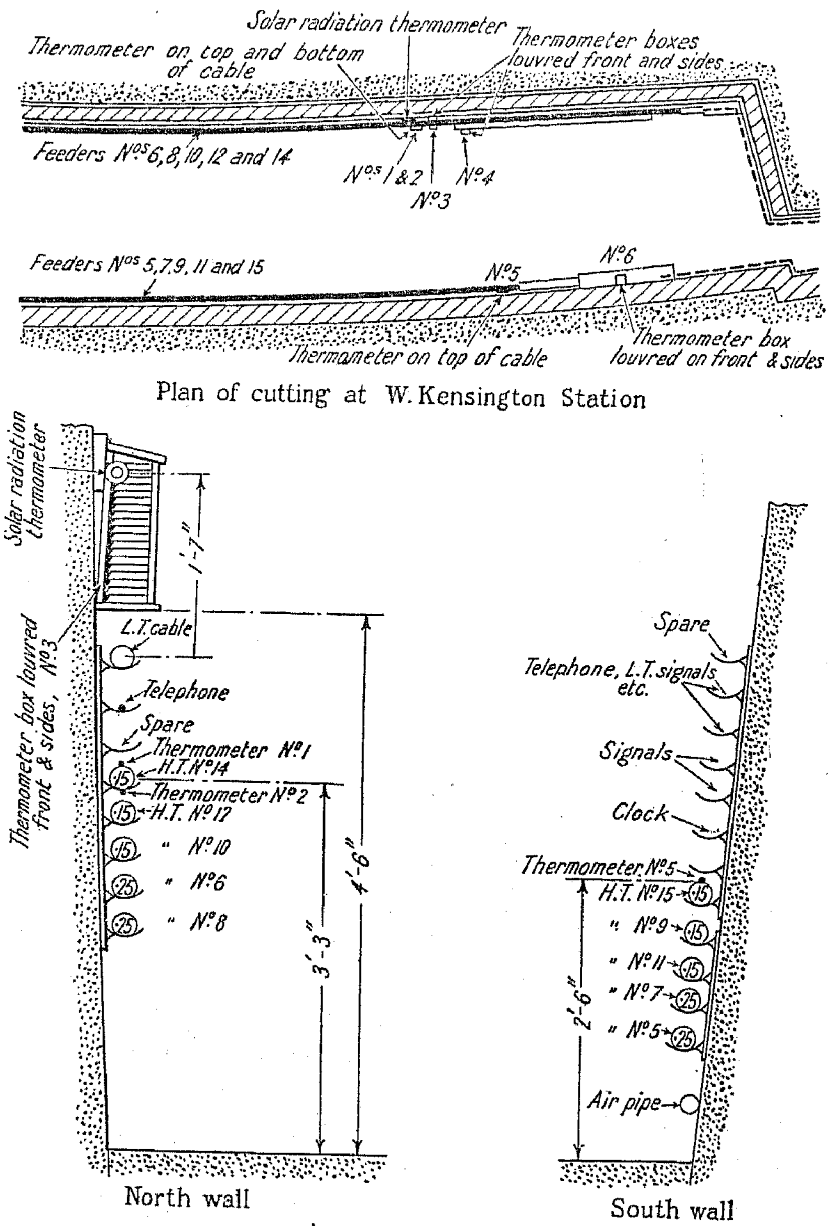


FIG. 7.—Plan and section showing elevation of walls of cutting at West Kensington station.

ciently in agreement to stabilize the factor F and obviate immediate research.

Noting the differences due to the difference in climatic conditions at London and Milan, it is safe to assume that the close agreement shown by the highest of the London figures with the Milan tests is due to the atmospheric and solar-radiation conditions being approximately identical.

The curve for the factor F, for bare lead-covered cables of 2 to 7 cm diameter, can therefore be taken as satis-

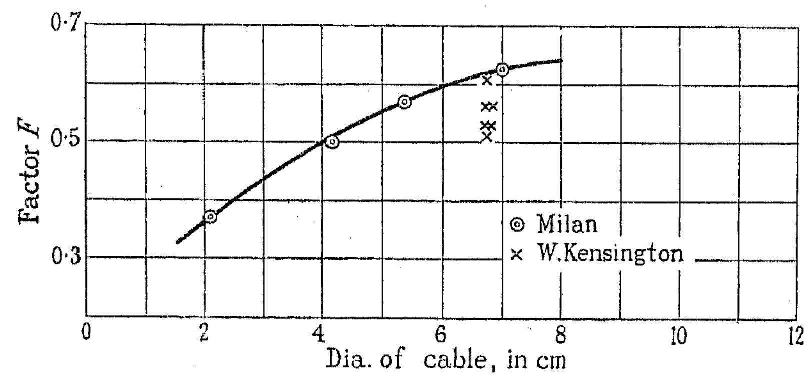


FIG. 9.—Bare lead-covered cables.

factory for Great Britain, because the curve corresponds to conditions which are extreme in this country and thus allows a good safety margin. It is probably suitable for general use.

Armoured Cables (*4 to 7 cm diameter*).

The Buenos Aires results, shown in Fig. 10, give considerably smaller values for F than those obtained at Milan, thereby indicating that the atmospheric conditions in the two places are not identical.

Also, it is obvious from Table 4 that the thermal conductivity of the material comprising the surface of the armoured cable is low, and the surface difference of the cables tested at these two places may explain the dis-

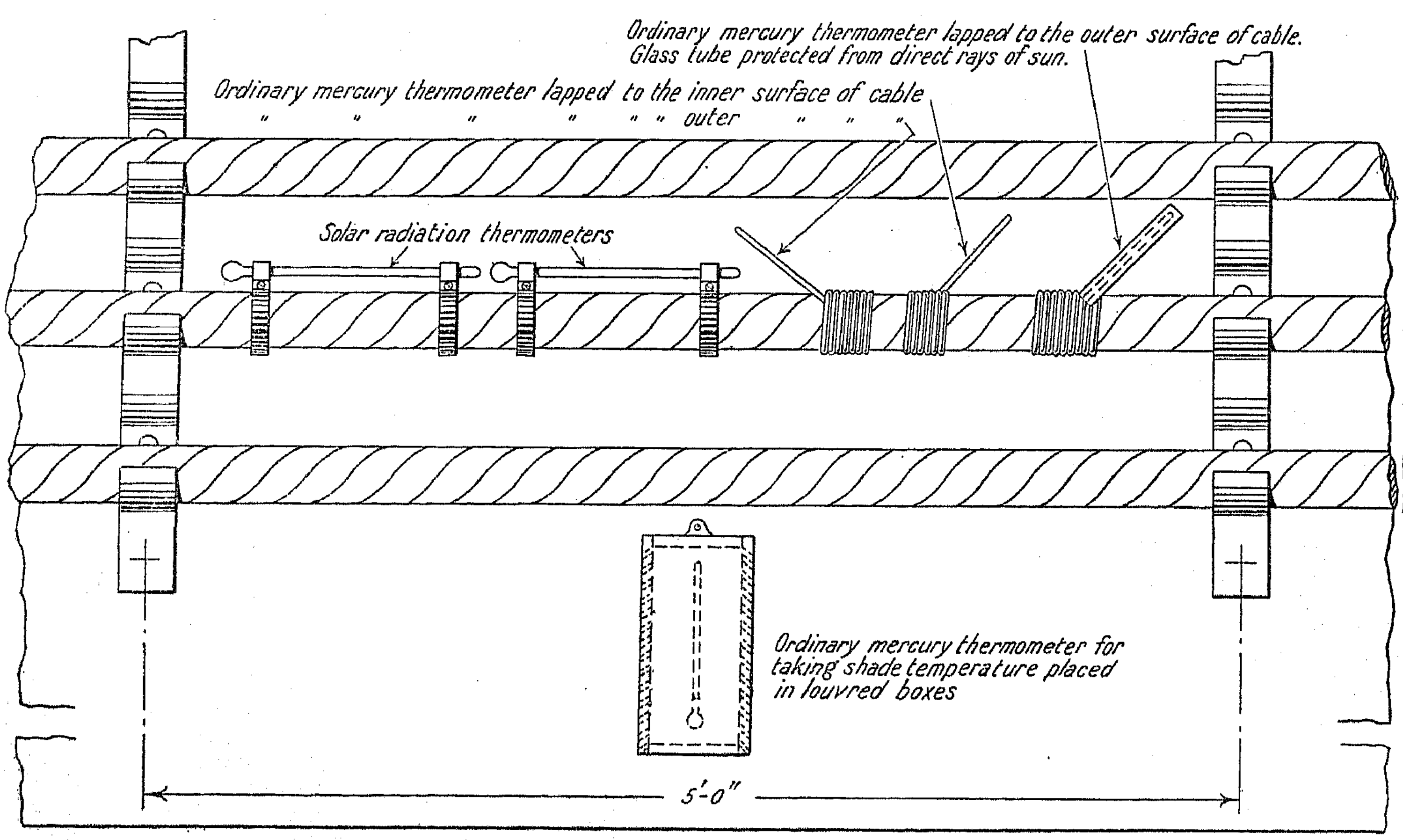


FIG. 8.—Front view of cables and thermometers.

crepancy. On the other hand, the Buenos Aires temperatures were measured with mercury thermometers taped to the surface of the cable. It is probable, therefore, that appreciable differences of temperature existed between the surface exposed to the sun and the adjacent thermometer bulb. These differences do not occur when thermocouples are used for making the measurements, as in Italy.

This combination of probabilities shows that the work done on armoured cables is not sufficiently advanced, and indicates the need for further research. In the interim, the Milan results (Fig. 10) for cables from 4 to 7 cm diameter are sufficiently satisfactory as a preliminary guide.

TABLE 4.

Temperatures of Cable Surfaces.

Diameter of cable (cm)	Description of cable	Temperature-rise (in deg. C.) of:— Surface jute-served	Lead	Iron
6·7	Lead-covered, single-wire armoured, jute served ..	29	14	—
6·0	Lead-covered, steel-tape armoured, jute served	28	—	—
4·8	Lead-covered, double-wire armoured, jute served	24	—	12
4·5	Lead-covered, steel-tape armoured, jute served	—	11	—
3·7	Lead-covered, single-wire armoured and braided	—	8	—

TABLE 5.

Solar Radiation at Various Latitudes.

Locality	Latitude	Highest monthly mean value of intensity of solar radiation over a period of years	Average value of intensity of solar radiation during tests	Highest rise of temperature of solar-radiation thermometer observed during tests, corrected to standard condition	Estimated highest rise of temperature of solar-radiation thermometer, based on Italian tests
	degrees	mW per cm^2	mW per cm^2	deg. C.	deg. C.
Batavia	5	109	—	—	36
Cairo	30	119	—	—	40
Buenos Aires	35	?	?	28	?
Ottawa	45	85	—	—	28
Modena	45	106	92	30	35
Florence	44	109	—	—	36
London	51·5	89 (in 1921)	?	36	30

TABLE 6.

Energy Required to Heat Cables.

Diameter of cable	Kind of cable	Energy required to heat 1 metre length of cable in shade to the same temperature as that attained in sunshine (A)	Total solar energy falling on 1 metre length of cable during tests (B)	Absorptive power of surface of cable (A/B)
cm		watt-sec.	watt-sec.	
7·0	Bare lead-covered	37·5	64·4	0·58
5·4	Bare lead-covered	26·0	50·0	0·52
2·1	Bare lead-covered	10·0	19·3	0·52

(7) TEMPERATURES BELOW THE SURFACE OF ARMOURED CABLE.

Table 4 indicates the temperature-rise underneath the surface of armoured cables investigated in Italy. These temperatures, taken at the same time as the surface temperature, were measured with thermocouples.

(8) Comparative Values of the Intensity of Solar Radiation in Different Latitudes.

To estimate the highest likely rise of temperature of a cable from the data given in Fig. 9, it is necessary to know the maximum rise in temperature of a solar-radiation thermometer at the position in question. This depends, almost entirely, on the value of the intensity of solar radiation. Data concerning this quantity are given in Table 5, col. 3.

The intensity of solar radiation is measured at official meteorological stations by means of Ångstrom's pyrheliometers, and is expressed as the number of milliwatts falling on 1 cm^2 of a surface normal to the direct rays of the sun. It can also be measured by means of the solar-radiation thermometer; the use of this instrument has been abandoned for precise meteorological measurements, but it is sufficiently accurate for the present tests.

The assumption that the reading of a solar-radiation thermometer is proportional to the incident intensity of solar radiation may involve an error of about 3 per cent when high readings are considered. When the rise of temperature of the bulb of the radiation thermometer above ambient temperature is relatively large, the rate

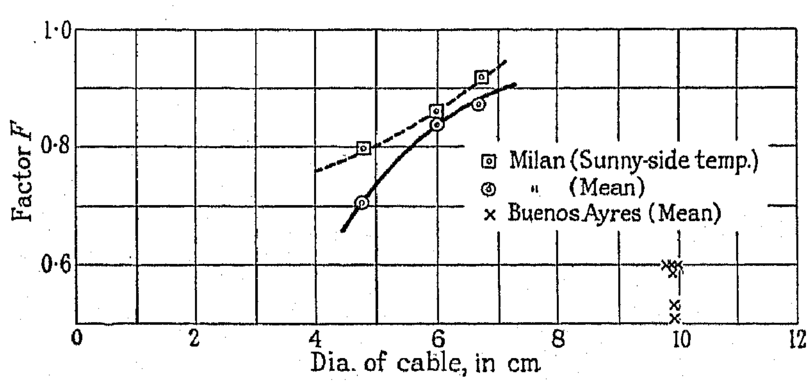


Fig. 10.—Armoured cables. Curves showing values of factor F for various sizes of cable corresponding to wind velocities of 1 m.p.h.

of emission by the bulb increases more rapidly than the increase of temperature-rise (Stefan's law). This error, however, is negligible compared with possible errors due to other factors.

It is reasonable to assume, therefore, that the temperature indicated by a solar-radiation thermometer is approximately proportional to the intensity of incident radiation. The average value of the solar-radiation intensity observed by Emanueli during his tests was 92 milliwatts per cm^2, and the highest rise of temperature above ambient of the solar-radiation thermometer was 30 deg. C. From this it may be deduced that the rise of temperature of a solar-radiation thermometer in deg. C. will be 0·33 times the intensity of solar radiation in milliwatts per cm^2. Using this factor, the values of the solar-radiation intensities given in Table 5, col. 3, have been converted to the rise of temperature of solar-radiation thermometers in col. 6.

It will be noted that the estimate for London is lower than the observed value. The variations in the last two columns in the table, while partly due to differences of geographical position, give an idea also of the accuracy at present obtainable in work of this kind. The figures suggest a limit of 33 deg. C. for general use, save where conditions are exceptionally severe.

(9) Energy Exchanges in the Heating of Cables.

The tests in Italy were amplified by measuring the electrical energy required to heat bare lead-covered cables in the shade to the same values as those attained by exposure to the sun. Similar tests for armoured cables are to be carried out later.

Using these values, together with the average value of the solar-radiation intensity, it is possible to calculate the absorptive power of the cable surface for solar rays, thus providing a rough check on the figures, since the absorptive power should be the same for each cable, independent of diameter.

The solar energy absorbed per metre length of the cable is given by the equation $H = aEA$, where a = absorptive power for solar rays; E = intensity of solar radiation, in watts per cm^2; and A = projected area (cm^2) of 1 metre length of cable, assuming the sun's rays to fall on it normal to its axis. The calculated values of H are given in Table 6.

It follows, therefore, that by decreasing the absorptive

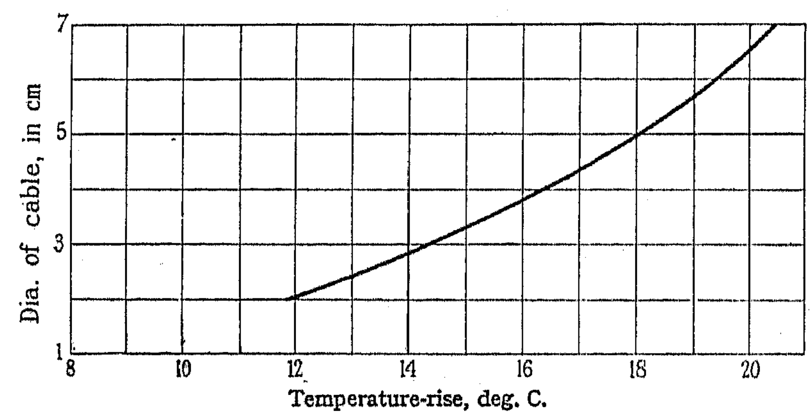


Fig. 11.—Bare lead-covered cable. Curve showing the relation between the diameter of the cable (cm) and its temperature-rise (deg. C.) above ambient temperature, taking the maximum rise of the solar-radiation thermometer as 33 deg. C. above ambient.

power of the surface the rise of temperature of the cable cover will be reduced. This result may be attained by suitably painting the surface with a white colour, thereby providing a surface of minimum absorptive power.

(10) Conclusion.

Bare Lead-Covered Cables.

The general agreement obtained from the results for bare lead-covered cables justifies the use of the factor F (Fig. 9), and, for the time being, obviates the necessity for further research.

Armoured Cables.

The results obtained (Fig. 10) do not justify any definite assertion as to the relationship between the diameter of armoured cables and the factor F. Further experimental work should be proceeded with in order to establish definitely the relationship between F and the diameter of the cable. The Italian results point to the fact that the use of thermocouples for measuring the surface temperature of the cables is more satisfactory than obtaining these figures with thermometers.

It is felt, however, that the Italian curve for the factor F can be used with a fair amount of certitude, within

the limitations of the diameters of the cables tested in that country.

Within a few degrees, a reading of 33 deg. C. can be taken as the maximum rise of the solar-radiation thermometer above ambient temperature.

Applying this assumption to the curves given for Figs. 9 and 10, the curves in Figs. 11 and 12 have been replotted on a scale of degrees, showing the relation between the cable diameter and the rise in temperature, in deg. C., of the cable above ambient temperature.

The Association is greatly indebted to Mr. L. Emanueli, Messrs. A. R. Cooper and C. E. Squire (London Electric Railways), and Messrs. J. Wilson and W. Wright (Buenos Ayres Western Railway), for the experimental work on which this report is based.

Acknowledgment is also due to Mr. A. Morris Thomas for the mathematical work given in Appendix III, and to Mr. S. H. Richards for its compilation.

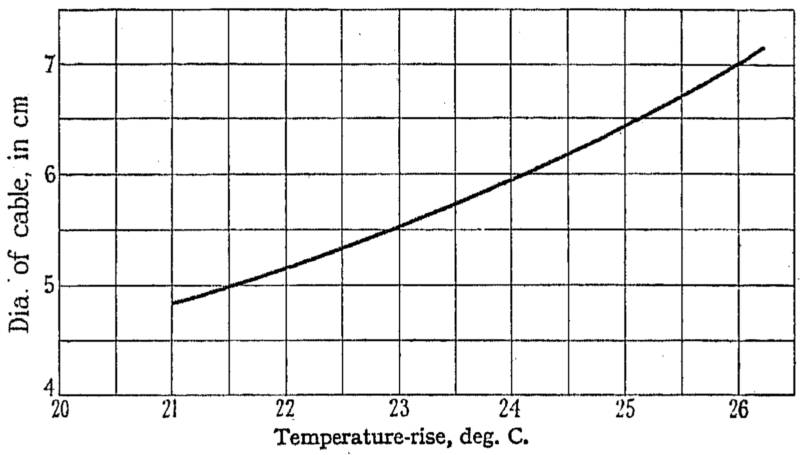


FIG. 12.—Armoured cable. Curve showing the relation between the diameter of the cable (cm) and its temperature-rise (deg. C.) above ambient temperature, taking the maximum rise of the solar-radiation thermometer as 33 deg. C. above ambient.

APPENDIX I.

INTERPRETATION OF THE READINGS OF A SOLAR-RADIATION THERMOMETER.

As certain discrepancies had been observed in the readings of the two solar-radiation thermometers used in London, it was decided to investigate the indications of a solar-radiation thermometer.

It is obvious that only one side of the bulb is subjected to direct radiation, whereas the shady side exchanges radiation with its surroundings and the sunny side must also do so with the sky generally. It follows that the temperature reached gives a hybrid indication and can only be used, even for comparative purposes, provided some control of the surroundings is exercised.

Certain tests were therefore made to bring out the main points. Wherever two instruments were used, the readings were corrected in terms of the one known to be the more sensitive.

(a) Direct versus Indirect Radiation.

One thermometer was mounted in a large shaded packing-case which was allowed to take shade temperature. A hole was made in the side of the packing-case and in the shading screen to admit a beam of direct light falling on the bulb only (Condition 1).

A second thermometer was mounted a few inches from a wall and about 18 in. from the ground, freely exposed, save that the bulb was screened from direct radiation by a small disc arranged to cast a full shadow upon it (Condition 2).

A comparison was then made between the temperature-rise above shade temperature due to direct radiation on one side of the bulb and that due to indirect radiation from all sides. The average ratio of the readings so obtained was 1·0 : 1·0, the readings being 19·2 and 18·9 respectively with a clear sky.

(b) Indirect versus (Direct + Indirect) Radiation.

Two radiation thermometers were mounted a few inches from a wall exposed to the sun and about 18 in. from the ground. One was freely exposed (Condition 3), and the other was protected from direct radiation only, by a small disc arranged to cast a shadow covering the bulb (Condition 2); thus one received direct and indirect radiation, and the other indirect radiation only. There were clouds covering part of the sky, but not before the sun.

The average ratio of the temperature-rise above shade temperature of the unscreened instrument to that of the screened instrument was 2·1 : 1·0, the average readings being 21·3 and 10·3 respectively with a cloudy sky.

(c) Direct versus (Direct + Indirect) Radiation.

One thermometer was exposed in a box (as in Condition 1), and the other freely exposed (as in Condition 3).

The ratio of the rises obtained was 2·55 : 1·0; varying from an average of 2·3 : 1·0 with readings 9·5 and 21·7 for a clear dull sky, to 2·80 : 1·0 with readings 7·1 and 19·8 for a cloudy dull sky.

(d) Examination of Results.

If the temperature-rise above normal depended in each case only upon the radiation received, then we should deduce from *(a)* equality of direct and indirect radiation and we should expect a ratio of 2 : 1 in *(b)* and in *(c)*. The surroundings in each case, however, except where the packing-case was used, were themselves at a higher temperature than shade temperature, and thus would furnish by their radiation due to their own temperature a datum line above shade temperature. Where the packing-case is used the whole bulb is exposed to surfaces at shade temperature. In the other cases the sky and walls and other surroundings, all at different temperatures, all subtend different angles at the bulb. One may conceive, however, a surround of uniform temperature giving an equivalent result. This may be described as an equivalent surround temperature, and the rises due respectively to direct and indirect radiation from the sun must be measured from this equivalent temperature and not from shade temperature if consistent results are to be obtained. Thus in these cases we have an initial temperature-rise θ. Any attempt to deduce θ from the data shows that it was not constant, and that the ratio of direct to indirect radiation cannot have been constant.

It will be understood that the actual radiation from the sun is substantially constant, but that the radiation received is greatly modified during passage through the

atmosphere. Thus low readings indicate large reductions, and vice versa. Further, the indirect radiation also varies, being assisted by the presence of clouds. It is well known that frosts at night are especially liable to occur when the sky is clear and the relative humidity low. Thus the radiation received from a clear sky is relatively low. This is upheld by the experience of the photographer, who expects low illumination in the shade when the sky is clear and relatively even distribution with a cloudy sky and partly obscured sun.

To make any direct comparison of results it has to be allowed that the temperature-rise due to direct radiation (d), that due to the indirect or reflected radiation (r), and the initial temperature-rise (θ), are all variables. In the following comparison the above facts as to the effect of atmosphere and clouds have been considered in conjunction with the recorded data, and several degrees of direct and indirect radiation and of resultant initial temperature-rise (θ) have been recognized. Four grades of d are recognized, two of r, and two of θ; there are also the constants deduced from the four experimental cases cited above. The following values are obtained.

(1) From test (a):—

$$d_4 = r_1 + \theta_2$$

(2) From test (b):—

$$d_3 + r_1 + \theta_1 = 2\cdot 1(r_1 + \theta_1)$$
$$\therefore \quad d_3 = 1\cdot 1(r_1 + \theta_1)$$

(3) From test (c):—

$$2\cdot 3d_2 = d_2 + r_2 + \theta_1$$
$$\therefore \quad d_2 = 0\cdot 77(r_2 + \theta_1)$$

also

$$2\cdot 8d_1 = d_1 + r_2 + \theta_1$$
$$\therefore \quad d_1 = 0\cdot 55(r_2 + \theta_1)$$

Scheduling the above equations in ascending order of d, they are as follows:—

$$\begin{aligned} d_1 &= 0\cdot 55(r_2 + \theta_1) \\ d_2 &= 0\cdot 77(r_2 + \theta_1) \\ d_3 &= 1\cdot 1(r_1 + \theta_1) \\ d_4 &= 1\cdot 0(r_1 + \theta_2) \end{aligned}$$

The results showed much bigger variations than had been expected; the experiments were devised and made on different days. It will be possible later, when radiation thermometers have been returned from abroad, to make a fresh series simultaneously with reliable instruments and get actual values for d, r, and θ. It is thought, however, that the above data will serve the immediate purpose, as the equations are consistent and lead to useful deductions.

(e) *Deductions.*

The experimental results bear out the theory that the maximum heating accompanies maximum direct radiation, which requires a clear atmosphere. Test (a) shows that under these conditions the indirect radiation may be expected to be somewhat less than the direct, as d is approximately equal to $r + \theta$, or not much greater, the total radiation having approached a maximum in that test. The following data enable an examination to be made of the probable value of θ, the equivalent initial temperature-rise of the surroundings.

(i) While tests (c) were being made, the conditions were changed by putting the radiation thermometer a few inches from the wall instead of 2 ft. This caused an average increase of 7 per cent in the observed rise above shade temperature, which would be due partly to contact with warmed air and partly to increase of the angle subtended by warmed surfaces. The maximum difference so observed was 10 per cent.

(ii) The temperature-rise of the air rising from the cables tested at West Kensington and Buenos Aires under steady maximum conditions was about 5 to 6 per cent of the rise shown by the radiation thermometer, and 4 to 5 per cent in the case of air rising over a warmed wall away from the cables.

Thus it is likely that the air alone is responsible for several per cent, say 5 per cent, of the rise shown by the radiation thermometer when mounted within a few inches of a large vertical surface. The heated surroundings subtending a larger angle are probably responsible for more than this, and the total value of θ for the conditions at West Kensington may well be $\frac{1}{6}$ of the reading of the radiation thermometer. At Buenos Aires the thermometer was largely surrounded by heated cables, and θ may well have reached $\frac{2}{3}$ the temperature of the cable or, say, $\frac{1}{3}$ of the radiation reading in the severest case.

The maximum readings of a solar-radiation thermometer give a fair basis for estimating the probable maximum temperature-rises of other bodies, provided the correlation is established under well-defined conditions.

The conditions at West Kensington were such that it is likely that $\frac{1}{6}$ of the temperature-rise observed on the radiation thermometer above shade temperature was due to the thermometer not being wholly surrounded by surfaces maintained at shade temperature.

At Buenos Aires the figure is likely to have reached $\frac{1}{3}$ or $\frac{2}{3}$ of the cable temperature.

The maximum heating of a body is likely to occur when the direct radiation is a maximum, i.e. when the atmosphere is clear and the sun is high, although the proportion of indirect radiation is then reduced.

APPENDIX II.

Sources of Error with Solar-Radiation Thermometers.

(a) *General Observations.*

The bulb of a solar-radiation thermometer is assumed to absorb all radiation falling upon it and to obey the law of exchanges in relation to surrounding objects. In practice, the surface does not have 100 per cent efficiency, and the presence of the glass bulb, more transparent to light than to heat, causes the apparatus to receive more readily than it emits.

The instrument can only be used to measure direct radiation provided it is surrounded by a surface maintained at shade or other known temperature, but under these conditions it will give no indication of indirect

radiation, which may amount to more than half the total received by a body near the earth's surface.

If it is used to indicate total radiation, its indications will depend upon its surroundings.

(*b*) *Errors in Instruments Employed.*

In one of the instruments used (instrument A) the diameter of the spherical bulb was about 2·2 times that of the attached neck and stem. In the other (instrument B) the bulb had a diameter of about 1·6 times the diameter of the stem and 1·8 times that of a short neck. The effect of the stems was such that the temperature-rises observed with the instruments in a horizontal position differed between the instruments by about 10 per cent, the instrument with the larger stem giving the lower reading in the vertical position.

The bulb of instrument B showed a slight gloss over most of its surface as compared with A, and some bright

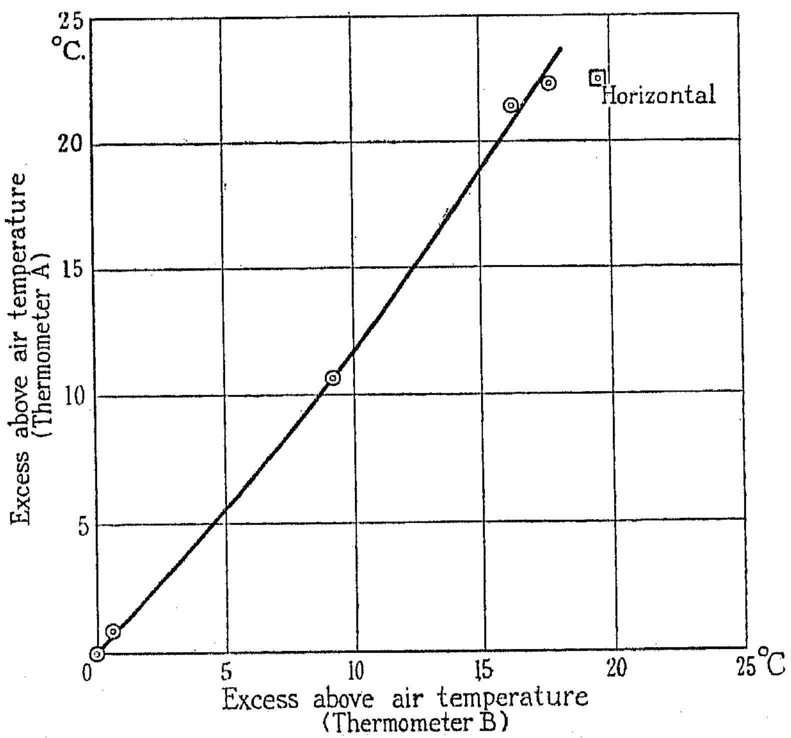


FIG. 13.—Comparison of solar-radiation thermometers used at West Kensington.

spots. The bulb of instrument A was nearly dead black, with very slight blemishes. It was estimated that bulb B had an efficiency of 95 per cent, and its readings were taken as standard. The readings observed on bulb B fall considerably below those of A, and owing to its smaller thermal capacity the bulb heated and cooled more quickly than bulb A. An interval of about 25 minutes, starting from cold, was necessary to secure a steady reading with bulb A. The instruments checked well when surrounded by the same heating surface in the neighbourhood of atmospheric temperature. No check was made at higher temperatures, the method of manufacture rendering this unnecessary.

To obtain a correlation the instruments were allowed to reach steady maxima simultaneously under several conditions. The comparison is given in Fig. 13, which has been used for correcting the observations made on instrument B.

Owing to irregularities of surface condition, no doubt the readings of thermometer B would vary somewhat on rotating the stem, but the surfaces were not critically examined before the tests. The instruments were, however, mounted in much the same positions, so that the scales were towards the front.

APPENDIX III.

Theory of the Rise of Temperature of a Cable Due to Exposure to Sunshine.

By A. Morris Thomas, B.Sc.

The temperature of a cable is maintained above that of ambient air, when exposed to sunshine, because its surface absorbs a substantial fraction of the solar radiant energy which falls upon it. The maximum absorption occurs when the sun's rays fall upon the cable in a direction normal to its axis, and is proportional to the area

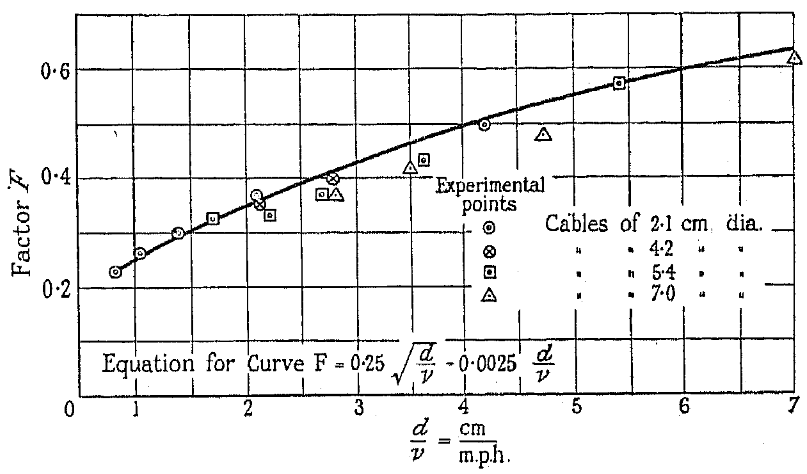


FIG. 14.—Bare lead-covered cables. Wind velocities 1–2½ m.p.h.

of the surface of the cable projected on to a plane perpendicular to the direction.

Let

H = energy absorbed per unit length of cable.
a = absorptive power of surface of cable.
E = intensity of solar radiation.
d = diameter of cable.
h = emissive power of surface of cable (energy radiated per sec. per deg. C. difference of temperature).
θ = mean difference of temperature (deg. C.) between cable surface and surrounding medium (i.e. ambient air).
A = a constant.
v = velocity of air (cm per sec.) over surface of cable in direction normal to its axis.
$\left.\begin{array}{l} r = \text{radiation} \\ c = \text{convection} \end{array}\right\}$(subscripts).

The energy absorbed per unit length of cable can be expressed by the equation

$$H = aEd \quad . \quad . \quad . \quad . \quad . \quad (1)$$

When the temperature of the surface of the cable has attained a constant value, the energy absorbed must be equal to the energy given off by radiation and convection.

Since the differences of temperature are small, Newton's

law of cooling may be assumed. Therefore, the heat given off by radiation per unit length of cable will be

$$H_r = \pi d h \theta \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

On Boussinesq's* theory of forced convection, a theory which has received a certain amount of support, the loss of heat by convection for a cylindrical surface is expressed by

$$H_c = A\theta(vd)^{\frac{1}{2}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Therefore for equilibrium we have the equation

$$H = H_r + H_c \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

or

$$\alpha E d = \pi d h \theta + A\theta(vd)^{\frac{1}{2}}$$

Therefore

$$\theta = \frac{\alpha E d}{\pi d h + A(vd)^{\frac{1}{2}}}$$

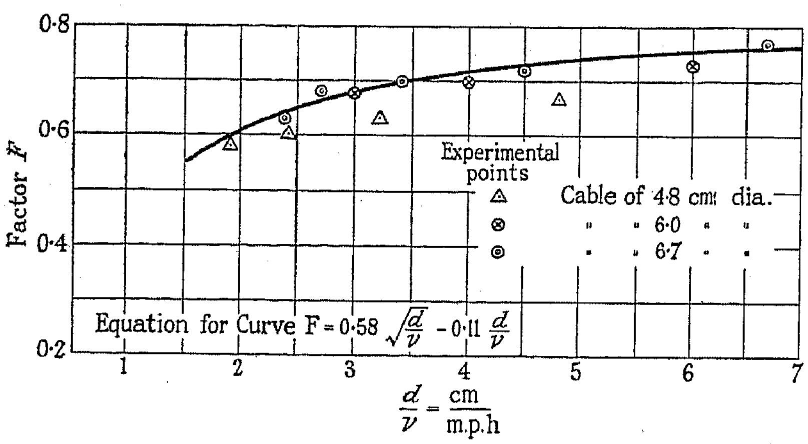


FIG. 15.—Armoured cables. Wind velocities 1–2½ m.p.h.

For the differences of temperature involved the quantity of heat lost by convection is large compared with that lost by radiation. Therefore the first term in the denominator of the fraction is small compared with the second, and the expression for θ can be written as follows:—

$$\theta = \frac{\alpha E d}{A(vd)^{\frac{1}{2}}\left[1 + \frac{\pi d^{\frac{1}{2}} h}{A v^{\frac{1}{2}}}\right]}$$

$$= \frac{\alpha E d^{\frac{1}{2}}}{A v^{\frac{1}{2}}}\left[1 - \frac{\pi d^{\frac{1}{2}} h}{A v^{\frac{1}{2}}}\right]$$

$$= \frac{\alpha E}{A}\left(\frac{d}{v}\right)^{\frac{1}{2}} - \frac{\pi \alpha E h}{A^2}\left(\frac{d}{v}\right)$$

* BOUSSINESQ: *Comptes Rendus*, 1901, vol. 133, p. 257 (see "Dictionary of Applied Physics," vol. 1, p. 471).

or

$$\theta = k_1\left(\frac{d}{v}\right)^{\frac{1}{2}} - k_2\left(\frac{d}{v}\right) \quad . \quad . \quad . \quad . \quad (5)$$

where k_1 and k_2 are constants for cables with the same kind of surface.

Equation (5) can be converted to an equation for F by dividing the corresponding rise of temperature of the solar-radiation thermometer.

Let

T_a = ambient thermometer indication, in °C.
T_c = cable thermometer indication, in °C. (mean value between sunny and shady sides).
T_r = solar-radiation thermometer indication, in °C.

Then

$T_r - T_a$ = solar-radiation thermometer temperature-rise above ambient, in deg. C.

and

$\theta = T_c - T_a$ = cable thermometer temperature-rise above ambient, in deg. C.

$$\therefore \quad \theta = T_c - T_a = F(T_r - T_a) \quad . \quad . \quad . \quad (6)$$

Therefore it follows from (5) that

$$\theta = F(T_r - T_a) = k_1\left(\frac{d}{v}\right)^{\frac{1}{2}} - k_2\left(\frac{d}{v}\right)$$

whence

$$F = k_3\left(\frac{d}{v}\right)^{\frac{1}{2}} - k_4\left(\frac{d}{v}\right) \quad . \quad . \quad . \quad . \quad (7)$$

where k_3 and k_4 are constants for cables with the same kind of surface.

It was found that Emanueli's results could be represented by the following equations:—

Bare Lead-Covered Cables:—

$$F = 0{\cdot}25\left(\frac{d}{v}\right)^{\frac{1}{2}} - 0{\cdot}0025\left(\frac{d}{v}\right) \quad . \quad . \quad . \quad (8)$$

Armoured Cables:—

$$F = 0{\cdot}58\left(\frac{d}{v}\right)^{\frac{1}{2}} - 0{\cdot}11\left(\frac{d}{v}\right) \quad . \quad . \quad . \quad (9)$$

These curves are represented by the curves shown in Figs. 14 and 15, in which the points derived from the mean curves drawn through the experimental results are also shown. The agreement is much more satisfactory for bare lead-covered cables than for armoured cables.

A NOMOGRAM FOR THE BAND PASS FILTER (ZOBEL TYPE).*

By A. T. STARR, M.A., B.Sc., and H. C. HALL, M.Sc.

(*Paper first received* 26*th January, and in final form* 19*th March*, 1934.)

SUMMARY.

A direct and very important method of designing band pass filters has been given by Zobel,† who finds that there are eight types of filter sections of special importance. In a later paper‡ Zobel gives methods for computing the attenuation of these sections: but these methods are fairly lengthy and it is very inconvenient to apply them to the various types of sections that are tried before a final design is achieved.

This paper gives a method for calculating the attenuation of the eight types of sections by means of a nomogram, so that the preliminary calculations can be made very quickly and easily and then the detailed calculation of Zobel can be applied to the final structure. The method employed simplifies the problem of design considerably.

GENERAL, LADDER-TYPE, BAND PASS FILTER SECTION.

A ladder-type network, in which the series arms are impedances Z_1 and the shunt arms impedances Z_2, can be made up by joining in series either T-networks with series arms $\frac{1}{2}Z_1$ and $\frac{1}{2}Z_1$ and shunt arm Z_2, or Π-networks with shunt arms $2Z_2$ and $2Z_2$ and series arm Z_1. Both

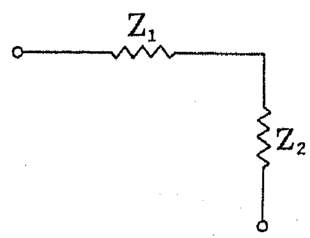


FIG. 1.

the T- and the Π-types can be represented symbolically by Fig. 1. The propagation constant of either type is 2 arc sinh $\sqrt{(Z_1/4Z_2)}$ or arc cosh $[1 + Z_1/(2Z_2)]$. Let the cut-off frequencies be $\omega_1/(2\pi)$ and $\omega_2/(2\pi)$. The frequency $\omega_m/(2\pi)$, where $\omega_m = \sqrt{(\omega_1\omega_2)}$, is called the mid-band frequency or just the mid-frequency. The impedance of the filter at the mid-frequency is taken as R, a pure resistance. It should be noted that the impedance is a pure resistance in the pass band and a pure reactance in the attenuating bands. Descriptions will now be given of the eight types of band pass filters designed by Zobel.

"CONSTANT k," BAND PASS FILTER, TYPE $4L_0U_\infty$.

A simple case is obtained by choosing Z_1 and Z_2 as inverse networks, so that Z_1Z_2 is a constant. It then follows that this constant must be equal to R^2. Fig. 2 shows Z_1 and Z_2 for this type of section. The elements are given by $L_{1k} = 2R/(\omega_2-\omega_1)$, $L_{2k} = R(\omega_2-\omega_1)/(2\omega_1\omega_2)$, $C_{1k} = L_{2k}/R^2$, and $C_{2k} = L_{1k}/R^2$.

The image impedance of the T-type section is

$$K_{1k} = \frac{R\sqrt{[(\omega_2^2 - \omega^2)(\omega^2 - \omega_1^2)]}}{\omega(\omega_2 - \omega_1)}$$

whilst that of the Π-type section is $K_{2k} = R^2/K_{1k}$. The propagation constant of either section is

$$\theta = 2 \text{ arc sinh} \frac{j\omega(1 - \omega_m^2/\omega^2)}{\omega_2 - \omega_1}$$

It follows from this that the attenuation decreases from infinity at $\omega = 0$ to zero at $\omega = \omega_1$, remains zero

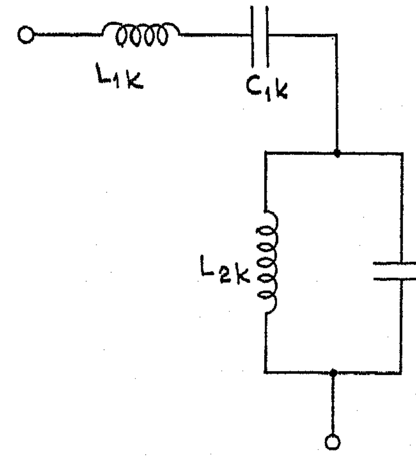


FIG. 2.—$4L_0U_\infty$.

between $\omega = \omega_1$ and $\omega = \omega_2$, and then increases to infinity at $\omega = \infty$. For this reason we label this section $4L_0U_\infty$: the number gives the number of elements in Z_1 and Z_2, L_0 indicates that the lower frequency of infinite attenuation is zero, and U_∞ shows that the upper frequency of infinite attenuation is infinite.

Zobel then goes on to find all the T-types of sections whose image impedance is K_{1k}, and all the Π-types whose image impedance is K_{2k}. These types will now be described.

GENERAL SECTION, TYPE 6LU.

This section, shown in Fig. 3, has six elements in Z_1 and Z_2, an arbitrary frequency of infinite attenuation between $\omega = 0$ and $\omega = \omega_1$, and another between $\omega = \omega_2$ and $\omega = \infty$. The elements are given by the following

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications (except those from abroad) should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† *Bell System Technical Journal*, 1923, vol. 2, p. 1.

‡ *Ibid.*, 1924, vol. 3, p. 567.

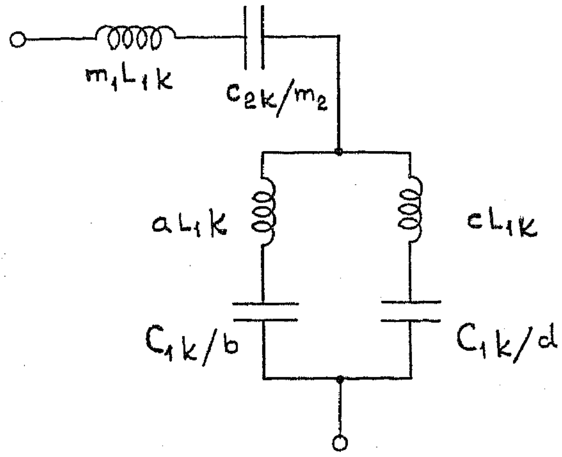


FIG. 3.—6LU.

equations, in which $g = \sqrt{[(1 - \omega_{1\infty}^2/\omega_1^2)(1 - \omega_{1\infty}^2/\omega_2^2)]}$ and $h = \sqrt{[(1 - \omega_1^2/\omega_{2\infty}^2)(1 - \omega_2^2/\omega_{2\infty}^2)]}$:—

$$m_1 = \frac{\omega_1\omega_2 g/\omega_{2\infty}^2 + h}{1 - \omega_{1\infty}^2/\omega_{2\infty}^2},$$

$$m_2 = \frac{g + \omega_{1\infty}^2 h/(\omega_1\omega_2)}{1 - \omega_{1\infty}^2/\omega_{2\infty}^2},$$

$$a = \frac{(1 - m_1^2)\omega_{2\infty}^2(1 - \omega_{1\infty}^2/\omega_{2\infty}^2)}{4g\omega_1\omega_2},$$

$$b = a\omega_{1\infty}^2/(\omega_1\omega_2), \quad d = ag/h, \quad \text{and} \quad c = d\omega_1\omega_2/\omega_{2\infty}^2.$$

TYPE $3L_0$.

This section is shown in Fig. 4. In this case $\omega_{1\infty} = 0$

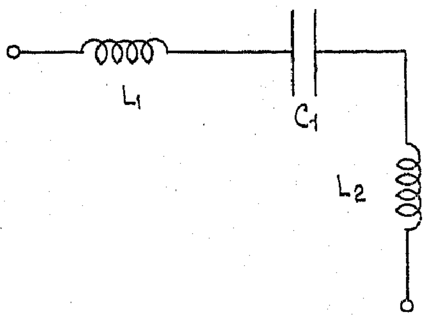


FIG. 4.—$3L_0$.

and there is no upper frequency of infinite attenuation:

$$L_1 = 2R\omega_1/[(\omega_2 - \omega_1)\omega_2], \quad C_1 = (\omega_2 - \omega_1)/(2R\omega_1\omega_2)$$

and $$L_2 = (\omega_1 + \omega_2)R/(2\omega_1\omega_2).$$

TYPE $3U_\infty$.

This is shown in Fig. 5. Here $\omega_{2\infty} = \infty$ and there is no lower frequency of infinite attenuation:—

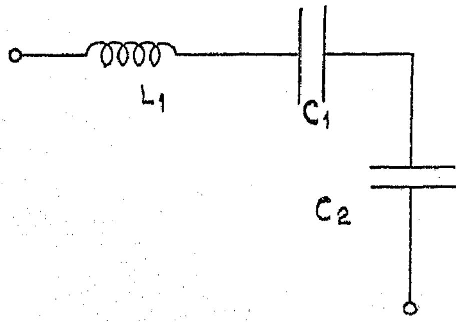


FIG. 5.—$3U\infty$.

$$L_1 = 2R/(\omega_2 - \omega_1), \quad C_1 = (\omega_2 - \omega_1)/(2\omega_1^2 R),$$

and $$C_2 = 2/[R(\omega_1 + \omega_2)].$$

TYPE 4L.

This is shown in Fig. 6. There is an arbitrary frequency of infinite attenuation below ω_1, but no frequency

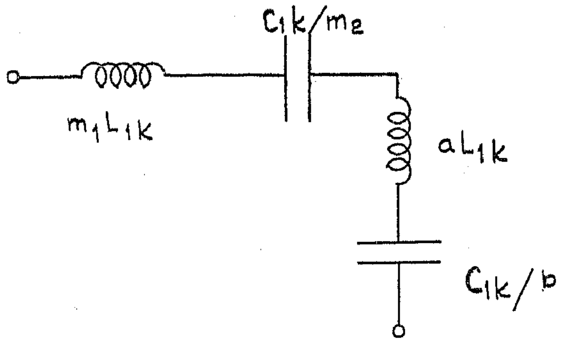


FIG. 6.—4L or 4U.

of infinite attenuation above ω_2. The elements are as shown, where

$$m_2 = \sqrt{\left(\frac{1 - \omega_{1\infty}^2/\omega_1^2}{1 - \omega_{1\infty}^2/\omega_2^2}\right)}, \quad m_1 = m_2\omega_1/\omega_2,$$

$$a = (1 - m_1^2)/(4m_1), \quad \text{and} \quad b = (1 - m_2^2)/(4m_2).$$

TYPE 4U.

This also is shown in Fig. 6. There is an arbitrary frequency of infinite attenuation above ω_2, but not below ω_1. The elements are as shown, where

$$m_1 = \sqrt{\left(\frac{1 - \omega_2^2/\omega_{2\infty}^2}{1 - \omega_1^2/\omega_{2\infty}^2}\right)}, \quad m_2 = m_1\omega_1/\omega_2,$$

$$a = (1 - m_1^2)/(4m_1), \quad \text{and} \quad b = (1 - m_2^2)/(4m_2).$$

TYPE $5L_0U$.

This is shown in Fig. 7. There is infinite attenuation

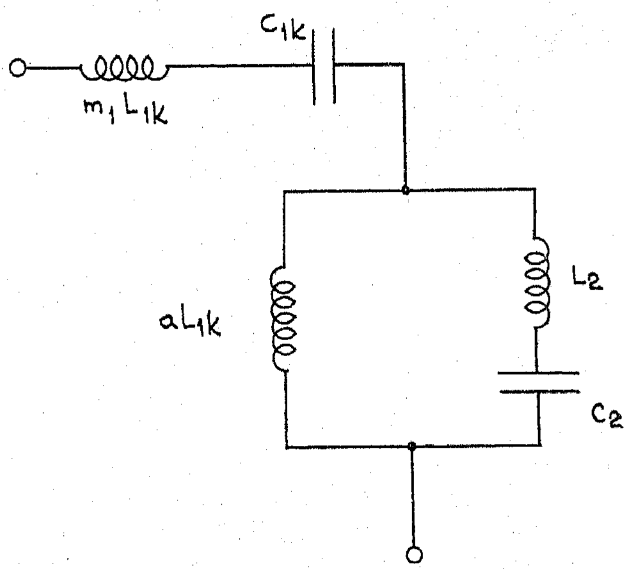


FIG. 7.—$5L_0U$.

at zero frequency and also at an arbitrary frequency above ω_2. The elements are given by

$$h = \sqrt{[(1 - \omega_1^2/\omega_{2\infty}^2)(1 - \omega_2^2/\omega_{2\infty}^2)]},$$

$$m_1 = h + \omega_1\omega_2/\omega_{2\infty}^2,$$

$$a = (1 - m_1^2)\omega_{2\infty}^2/(4\omega_1\omega_2),$$

$$L_2 = L_{1k}[a\omega_1\omega_2/(h\omega_{2\infty}^2)], \quad C_2 = C_{1k}h/a.$$

TYPE 5LU∞.

This is shown in Fig. 8. There is infinite attenuation

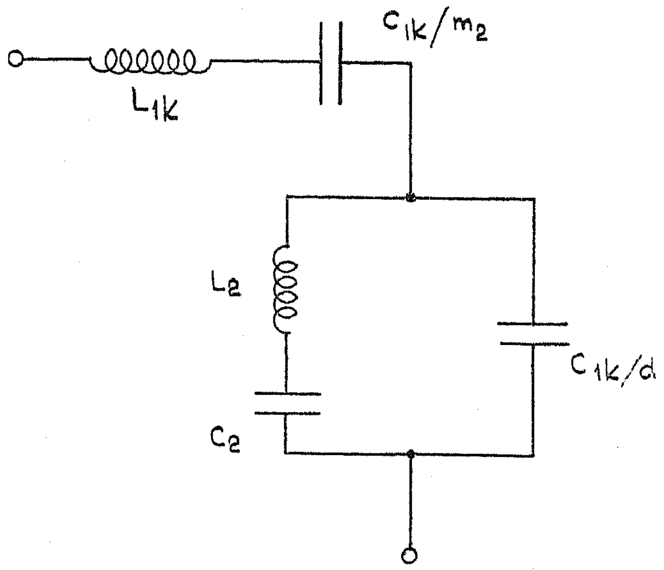


FIG. 8.—5LU∞.

at an arbitrary frequency below ω_1 and also at infinite frequency:

$$g = \sqrt{[(1 - \omega_1^2/\omega_{2\infty}^2)(1 - \omega_2^2/\omega_{2\infty}^2)]},$$
$$m_2 = g + \omega_{1\infty}^2/(\omega_1\omega_2),$$
$$d = (1 - m_2^2)\omega_1\omega_2/(4\omega_{1\infty}^2),$$
and
$$L_2 = L_{1k}d/g, \quad C_2 = C_{1k}[g\omega_1\omega_2/(d\omega_{1\infty}^2)].$$

DESIGN DATA.

The eight types of sections just described are used in practice and it is therefore necessary to possess adequate data for their use. It is impossible to draw attenuation/frequency curves for all types of sections. The arrangement of the data is simplified by certain simple relations between the propagation constants of the sections.* Let the propagation constant of the section 6LU be written θ(6LU), and so on. Then the relations are as follows:—

$$\theta(\mathrm{6LU}) = \theta(\mathrm{4L}) + \theta(\mathrm{4U}),$$
$$\theta(\mathrm{5L_0U}) = \theta(\mathrm{3L_0}) + \theta(\mathrm{4U}),$$
$$\theta(\mathrm{5LU_\infty}) = \theta(\mathrm{4L}) + \theta(\mathrm{3U_\infty}),$$
and
$$\theta(\mathrm{4L_0U_\infty}) = \theta(\mathrm{3L_0}) + \theta(\mathrm{3U_\infty}).$$

These relations hold provided the frequencies of infinite attenuation on one side of the equation are the same as those on the other side. Thus in the second equation the frequencies of infinite attenuation are zero and an arbitrary $\omega_{2\infty}/(2\pi)$: then the frequencies on the right-hand side are zero (in the section $3L_0$) and the same arbitrary $\omega_{2\infty}/(2\pi)$ (in the section 4U). Thus any section with a lower and an upper frequency of infinite attenuation is equivalent to the tandem combination of two simpler sections, one of which has the lower frequency of infinite attenuation and the other the upper frequency. It is therefore necessary to consider only sections of the types 4L and 4U; types $3L_0$ and $3U_\infty$ are merely special cases of these and, when suitable sections have been found to yield the desired attenuation/frequency curve, the sections can be grouped in pairs and replaced by the types 6LU, $5L_0U$, $5LU_\infty$, and $4L_0U_\infty$ in order to produce the most economical practical design.

There is another theorem* which simplifies the work still further. It is expressed in the following terms. "The propagation constant at $\omega/(2\pi)$ of a section 4L, whose frequency of infinite attenuation is $\omega_{1\infty}/(2\pi)$, is equal to the propagation constant at $\omega_m^2/(\omega \times 2\pi)$ of a section 4U, whose frequency of infinite attenuation is $\omega_m^2/(\omega_{1\infty} \times 2\pi)$. Conversely the propagation constant at $\omega/(2\pi)$ of a section 4U, whose frequency of infinite attenuation is $\omega_{2\infty}/(2\pi)$, is equal to the propagation constant at $\omega_m^2/(\omega \times 2\pi)$ of a section 4L, whose frequency of infinite attenuation is $\omega_m^2/(\omega_{2\infty} \times 2\pi)$."

It is necessary, therefore, to possess data for the type 4L or 4U only, and then simple combinations, according to this theorem and the equations of equivalence, yield the data for the eight types of sections.

ATTENUATION FOR SECTION 4L.

In this section we have

$$Z_1 = j\omega m_1 L_{1k} + m_2/(j\omega C_{1k}),$$
$$Z_2 = j\omega a L_{1k} + b/(j\omega C_{1k}),$$

so that

$$Z_1/(4Z_2) = (\omega_1^2 - \omega_{1\infty}^2)(\omega_2^2 - \omega^2)/[(\omega_2^2 - \omega_1^2)(\omega_{1\infty}^2 - \omega^2)],$$

after substituting for L_{1k}, C_{1k}, m_1, m_2, a, and b.

The propagation constant is thus

$$\theta(\mathrm{4L}) = 2 \operatorname{arc\,sinh} \sqrt{\frac{(\omega_1^2 - \omega_{1\infty}^2)(\omega_2^2 - \omega^2)}{(\omega_2^2 - \omega_1^2)(\omega_{1\infty}^2 - \omega^2)}}$$
$$= A + jB, \text{ say.}$$

The pass band extends from $\omega_1/(2\pi)$ to $\omega_2/(2\pi)$, in which range

$$A = 0$$
and
$$B = -2 \operatorname{arc\,sin} \sqrt{\frac{(\omega_1^2 - \omega_{1\infty}^2)(\omega_2^2 - \omega^2)}{(\omega_2^2 - \omega_1^2)(\omega^2 - \omega_{1\infty}^2)}}$$

B, the phase-shift, is $-\pi$ at $\omega_1/(2\pi)$ and 0 at $\omega_2/(2\pi)$.

There are three attenuating regions:—

Region 1.

$0 \leq \omega < \omega_{1\infty}$. In this band $B = 0$ and

$$A = 2 \operatorname{arc\,sinh} \sqrt{\frac{(\omega_1^2 - \omega_{1\infty}^2)(\omega_2^2 - \omega^2)}{(\omega_2^2 - \omega_1^2)(\omega_{1\infty}^2 - \omega^2)}}$$

Region 2.

$\omega_{1\infty} < \omega \leq \omega_1$.

Here $B = -\pi$, and

$$A = 2 \operatorname{arc\,cosh} \sqrt{\frac{(\omega_1^2 - \omega_{1\infty}^2)(\omega_2^2 - \omega^2)}{(\omega_2^2 - \omega_1^2)(\omega^2 - \omega_{1\infty}^2)}}$$

Region 3.

$\omega_2 \leq \omega \leq \infty$.

Here $B = 0$, and

$$A = 2 \operatorname{arc\,sinh} \sqrt{\frac{(\omega_1^2 - \omega_{1\infty}^2)(\omega_2^2 - \omega^2)}{(\omega_2^2 - \omega_1^2)(\omega_{1\infty}^2 - \omega^2)}}$$

* O. J. ZOBEL: *Bell System Technical Journal*, 1923, vol. 2, p. 28.

* T. E. SHEA: "Transmission Networks and Wave Filters," p. 313. A proof is given by one of the present authors (A. T. Starr) in a forthcoming book, "Theory of Electric Circuits and Wave Filters."

The form of the attenuation, A, is the same in regions 1 and 3.

The three attenuating bands and the pass band must all be expressed on the nomogram.

Nomogram for Section 4L.

Let $x = \omega^2/\omega_m^2$, $y = \omega_2^2/\omega_m^2 = \omega_2/\omega_1$, $z = \omega_{1\infty}^2/\omega_m^2$.
Then in regions 1 and 3,

$$\sinh^2\frac{A}{2} = \frac{1 - yz}{y^2 - 1}\cdot\frac{y - x}{z - x} = u\frac{y - x}{z - x}.$$

The values of y and z determine the filter, so that for a given filter section u is a constant.

$$\log\sinh^2\tfrac{1}{2}A + \log(z - x) = \log u + \log(y - x)$$
$$= W\text{, say.}$$

Two nomograms are prepared, one for $W = \log(y - x) + \log u$ and one for $W = \log\sinh^2\tfrac{1}{2}A + \log(z - x)$,

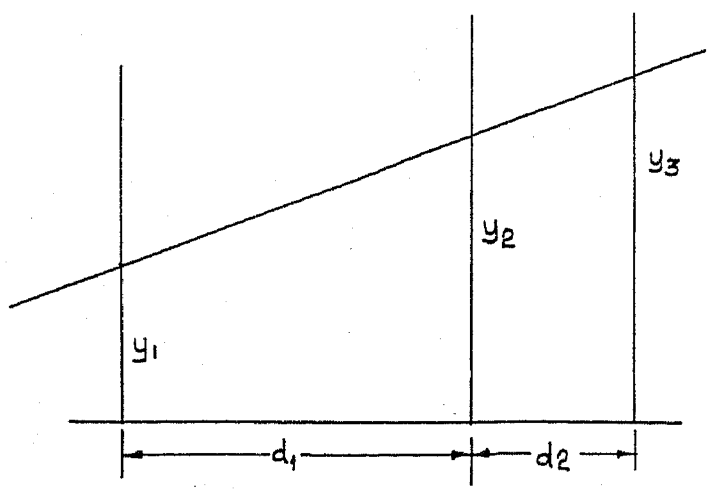


FIG. 9.

with a common scale for W which thus does not need evaluation.

Consider the parallel-line nomogram of Fig. 9. We have

$$(y_2 - y_1)/d_1 = (y_3 - y_2)/d_2$$

That is $\quad y_2 = y_3 d_1/(d_1 + d_2) + y_1 d_2/(d_1 + d_2)$,

which is of the form $W = \log(y - x) + \log u$, provided

$$y_2 = W,\quad y_3 = \left[(d_1 + d_2)/d_1\right]\log(y - x),$$

and $$y_1 = \left[(d_1 + d_2)/d_2\right]\log u.$$

We keep the same scale and line for $y_2(= W)$ and introduce new scales y_4 and y_5, as shown in Fig. 10. Here

$$y_2 = y_4(d_1' + d_2')/d_2' - y_5 d_1'/d_2'$$

which is equivalent to

$$W = \log\sinh^2\tfrac{1}{2}A - \log\left[1/(z - x)\right]$$

if $\quad y_2 = W,\quad y_4 = \left[\log\sinh^2\tfrac{1}{2}A\right]\left[d_2'/(d_1' + d_2')\right]$,

and $\quad y_5 = (d_2'/d_1')\log\left[1/(z - x)\right]$.

The following values were chosen for the d's: $d_1 = 2$, $d_2 = 4$, $d_1' = 2$, $d_2' = 1$.

We get

$$y_1 = (3/2)\log u,\quad y_3 = 3\log(y - x),$$
$$y_4 = \tfrac{1}{3}\log\sinh^2\tfrac{1}{2}A = \tfrac{2}{3}\log\sinh\tfrac{1}{2}A,$$

and $$y_5 = \tfrac{1}{2}\log\left[1/(z - x)\right].$$

In order to avoid a calculation for u, curves have been drawn so that u can be found graphically. Fig. 11 shows the complete diagram. To find u, we look for the point of intersection of the ordinate through z and the curve corresponding to y; a horizontal line through this point meets the axis of u at the required value, which is unspecified on the u axis since it need not be known. Thus the point on the u axis corresponding to $y = 1{\cdot}10$ and $z = 0{\cdot}64$ is shown as X at the end of the dotted line. This point, X, is fixed for the filter section that is determined by the given values of y and z.

To determine the attenuation at any frequency in region 1, in which $x < z$, we proceed as follows. We place a rule along the line joining X and the desired value of $y - x$. Suppose $x = 0{\cdot}4$; then $y - x = 0{\cdot}70$,

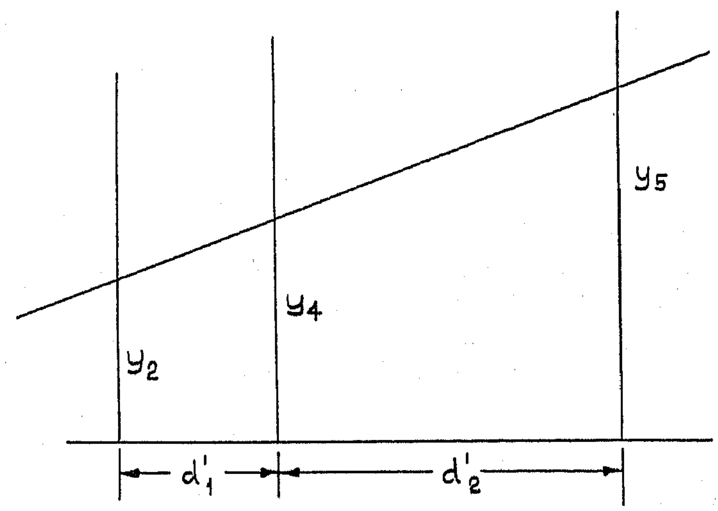


FIG. 10.

and the line is as shown. The rule intersects the axis of W at P. We lay the rule along P and the point on the $(z - x)$ axis which corresponds here to a value $z - x = 0{\cdot}64 - 0{\cdot}4 = 0{\cdot}24$. The rule intersects the axis of A at a point which corresponds to the value $2{\cdot}95$ on the right-hand side. The attenuation is then $2{\cdot}95$ nepers: this is correct to within $0{\cdot}05$ neper. The point on the attenuation curve of the filter is shown as Q in Fig. 12. At any frequency in region 1, $z - x$ and $y - x$ are both positive: the numbers on the right-hand side of the axis of A give the attenuation in nepers.

In region 3, $z - x$ and $y - x$ are both negative: but if we reverse the sign of both, the expression for the attenuation is the same as in region 1. We therefore find the attenuation as before, but we take the magnitudes of $z - x$ and $y - x$, disregarding the negative signs. Thus at $\omega = 1{\cdot}5\omega_m$ we have $x = 1{\cdot}5^2 = 2{\cdot}25$, $z - x = -1{\cdot}61$, and $y - x = -1{\cdot}15$. The dotted lines for this case are shown, and the attenuation is seen to be $1{\cdot}8$ nepers: the actual value is $1{\cdot}75$ nepers, and the accuracy is sufficient for all purposes. The corresponding point is Q′ in Fig. 12.

In region 2, $z - x$ is negative and $y - x$ is positive: also, there is a $\cosh^2$ in place of $\sinh^2$. By a method similar to that described above for regions 1 and 3, a nomogram is drawn using the same axes of u, W, and

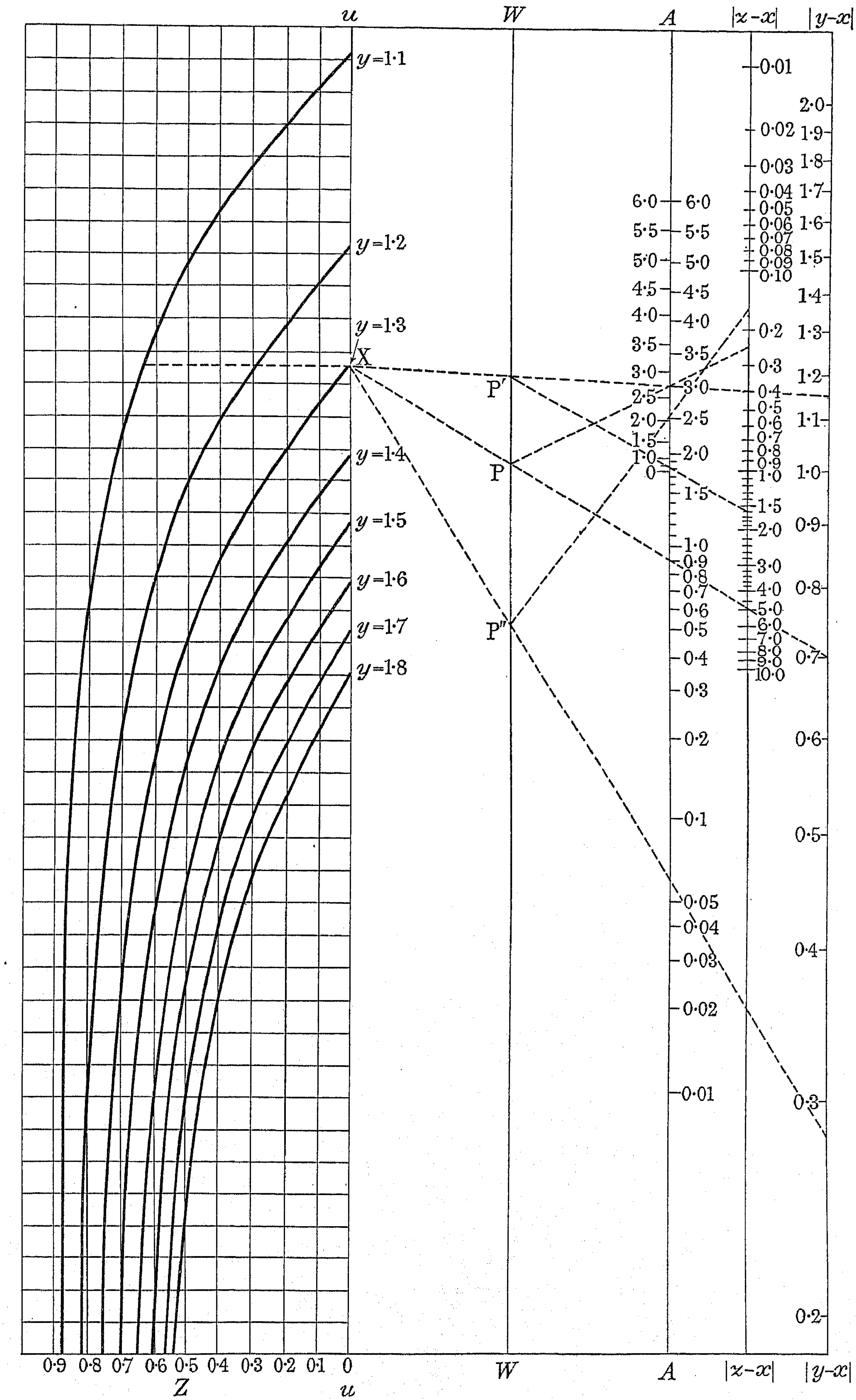

u
W
A
|z-x|
|y-x|
y=1·1
y=1·2
y=1·3
X
y=1·4
y=1·5
y=1·6
y=1·7
y=1·8
P′
P
P″
0·9 0·8 0·7 0·6 0·5 0·4 0·3 0·2 0·1 0
Z
u
W
A
|z-x|
|y-x|

FIG. 11.

$y - x$, but the axis of $z - x$ is replaced by an identical axis representing $x - z$ or $|z - x|$, whilst the axis of A is marked on the left-hand side. Thus at $\omega = 0 \cdot 9\omega_m$, $x = 0 \cdot 9^2 = 0 \cdot 81$, $|z - x| = 0 \cdot 17$, and $y - x = 0 \cdot 29$. The dotted lines for this case are shown (the point on the axis of W is here P″) and the attenuation is $2 \cdot 0$ nepers; which is correct. The corresponding point is Q″ in Fig. 12.

Résumé of Instructions for Use of Nomogram.

The filter section is determined by ω_1, ω_2, and $\omega_{1\infty}$. We calculate $y = \omega_2/\omega_1$ and $z = \omega_{1\infty}^2/(\omega_1\omega_2)$. The point X on the axis of u is obtained by finding the point of intersection of the curve with the given value of y and the ordinate through z, and then finding where the horizontal through this point meets the axis of u. The point X is marked, as it is used in every determination of attenuation for this filter section.

A rule is then laid along the line joining X and the point on the $|y - x|$ axis, and the point P in which the rule meets the axis of W is noted. The rule is laid along the line joining P and the point on the $|z - x|$ axis. The attenuation is read on the right-hand side of the axis of A at the point where the rule crosses, when $z - x$ and $y - x$ have like signs; but is read on the left-hand side when $z - x$ and $y - x$ have unlike signs.

As an example, Fig. 12 shows the attenuation/frequency curve for the section 4L, in which $y = \omega_2/\omega_1 = 1 \cdot 10$ and $z = \omega_{1\infty}^2/\omega_m^2 = 0 \cdot 8^2 = 0 \cdot 64$: the points on the curve have been found by the use of the nomogram. The time taken to draw the curve by the use of the nomogram was 7 minutes. By the Zobel method of computation the time taken is many times longer and the work is tedious.

The scale of A between $1 \cdot 0$ and 0 on the left-hand side is very crowded: this, however, is of no importance, because dissipation becomes important in this range of frequencies and the attenuation differs appreciably from the ideal value. Dissipation causes attenuation, with the result that the values from $1 \cdot 5$ or $1 \cdot 0$ neper down to 0 neper are widened out on the axis of A, the zero point going down to infinity.

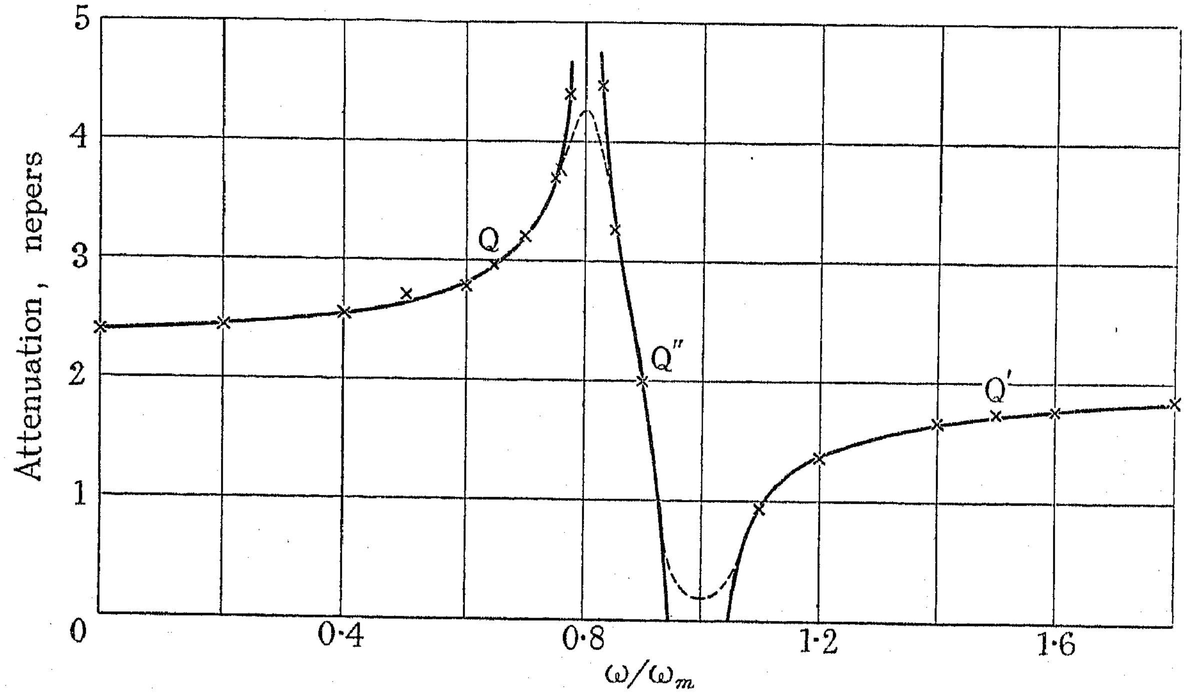


Fig. 12.

Similarly there is no point in putting in values of A above $6 \cdot 0$ nepers, as dissipation usually limits the attenuation per section to a much lower value than this.

An attempt is being made by the authors to construct a series of axes of A for different values of dissipation in the coils: the work entailed is laborious and the method is approximate only.

The attenuation curve, when dissipation is present, is of the shape shown by the dotted curve in Fig. 12. Dissipation affects the attenuation only in the ranges of frequency in which A is ideally zero or infinity.

The authors' acknowledgments are due to Messrs. Callender's Cable and Construction Co., Ltd., for permission to publish this work.

EXPERIENCE WITH, AND PROBLEMS RELATING TO, BOTTOM BEARINGS OF ELECTRICITY METERS.

By G. F. Shotter, Associate Member.

(*Paper first received* 12*th December*, 1933, *and in final form* 13*th March*, 1934; *read before the* Meter and Instrument Section 13*th April*, 1934.)

Summary.

The paper first outlines the results obtained over a period of 10 years with oiled sapphire-steel bearings on a single type of meter used by a large supply undertaking, and describes tests carried out on new and worn pivots and jewels with various lubricants and abrasives. The results indicate that oil greatly increases the life of a bearing, but that, even when oiled or greasy jewels are used, the presence of rust or debris is the major cause of wear and consequent errors in the reading of the meter.

A series of wear tests on various pivot materials, both oiled and dry, is next described. The results show that materials of all hardnesses give comparatively good results when oiled. No conclusive evidence is obtained of the validity of Stott's theory that oxygen is set free from sapphire under the influence of the large cohesive forces which operate in meter bearings.

The cause of surface cracking in sapphire jewels is then investigated, by means of a device which initiates impacts at the rate of 18 per minute between the pivot and the jewel of a meter bearing.

Finally, an account is given of apparatus designed for the rotational testing of meter bearings in air and inert atmospheres, providing special facilities for the microscopical examination of jewels. The results of tests in nitrogen, argon, neon, hydrogen, and a vacuum, are discussed, and it is concluded that further experimental work is necessary in order to confirm or disprove the sapphire-oxygen theory.

Introduction.

Although it might at first appear that an apology is necessary for introducing another paper on the subject of pivots and jewels for use in rotating meters, further consideration will show that while the problem of a long-life bottom bearing remains unsolved everything is to be gained by the publication of investigations carried out in an attempt to find a solution.

For the last 12 months the Electrical Research Association, in co-operation with both users and makers, have been carrying out an extensive research into the problems relating to the bottom bearings of electricity meters. The present paper is, however, a summary of the results of many years' work and experience in the Laboratories of the North Metropolitan Electric Power Supply Co.

The fact that the permanent magnets of the modern induction watt-hour meter are exceedingly stable implies that the supply companies stand to lose in the great majority of cases, owing to increased friction in the meter. The maintenance cost to the supply companies is determined by the length of time for which a meter can be left in service before an overhaul charge is incurred.

(1) Results of Ten Years' Experience of Oiled Bottom Bearings.

For some years the company with which the author is associated have been carrying out routine microscopic examinations of all pivots and jewels, whether new or returned from service. Full details as to the condition of the pivot and jewel, and the number of revolutions, have been recorded. As a result an insight has been gained into the behaviour of oiled bearings with revolutions amounting to possibly 30 millions and with a time period of 8 years.

The results have all been obtained on one type of meter, of which the full-load torque is 50 g-mm, and the rotor weight 16 g. Only synthetic-sapphire jewels, ball-ended steel pivots, and highly distilled mineral oil, have been used. No epilame has been applied to the meters under review. Although the results obtained from only about 4 000 jewels and pivots are reviewed in this paper, they represent the experience gained from probably 20 000.

The two questions that naturally arise in connection with oiled pivots and jewels are: (1) Does oil prevent the formation of rust? and (2) What state is the oil in after, say, 8 years' service? The first question is probably best answered by the curve shown in Fig. 1, which indicates the percentage of jewels and pivots, lubricated with grease or oil, on which rust has been found; this percentage is plotted against the number of revolutions. It will be seen that the resulting curve is practically linear.

The number of pivots and jewels analysed is 4 315, made up as shown in Table 1. In explanation of Fig. 1 it should be mentioned in the first place that experience suggests that slight differences in the polish of the jewel would not affect the curve; secondly, the radii of the pivots and jewels were, within practical limits, all equal; thirdly, the rotor weight was constant; and finally, the polish and material of the pivot were the same throughout. It would seem, therefore, that some other explanation of the curve has to be found.

According to Mr. Stott,* the orientation of the optic axis is an important factor in relation to wear. Assuming that this is the predominant factor, and that the proportion of jewels cut with different optic axes is the same over the period chosen for the analysis, the curve shown in Fig. 1 is of the type which might be expected. The meters in the analysis had been in service for an average of about 7 years. As the revolutions increased, the percentage of jewels showing rust also increased.

* *Collected Researches of the National Physical Laboratory*, 1931, vol. 24, p. 1.

Even jewels cut with the optic axis in the best possible orientation would ultimately form rust.

The photomicrographs shown in Figs. 2 and 3 (Plate 1, facing page 756) indicate the condition of the pivots and jewels; in Fig. 2 there are no signs of rust, while Fig. 3 represents an average condition of a rusty, greasy jewel. The grease apparently has the characteristics of vaseline, most of it being found just off the running circle of the pivot. Fig. 3 shows that the major portion of the rust and grease is upon the walls of the jewels, there being a greasy or rusty-greasy centre.

To enable comparative values of accuracy to be obtained with jewels and pivots run under the above two conditions, tests were carried out on 7 jewels and pivots, none having been touched in any way after being taken out of service meters. These jewels showed clean grease only; and no sign of rust. The difference obtained between these 7 pivots and jewels, and the mean of 3 new pivots and jewels in perfect condition, are shown in Fig. 4(*a*), where the average, fast, and slow limits are given.

The results of the tests on the rusty grease are shown in Figs. 4(*b*) and 4(*c*), which give the results of tests on 15 meters. The average values and the fast limit are given in Fig. 4(*b*) and (*a*), and the slow limit in Fig. 4(*c*). The latter curve only applies to one pivot and jewel, upon which further tests will be described later. The average number of revolutions on the clean-grease pivots and jewels was 11·3 millions, the minimum being 8 millions and the maximum 20 millions. On the rusty jewels the average was 12 millions, the minimum being 8·6 millions and the maximum 23 millions. It is gratifying to note that even when rusty grease is present the errors are very small.

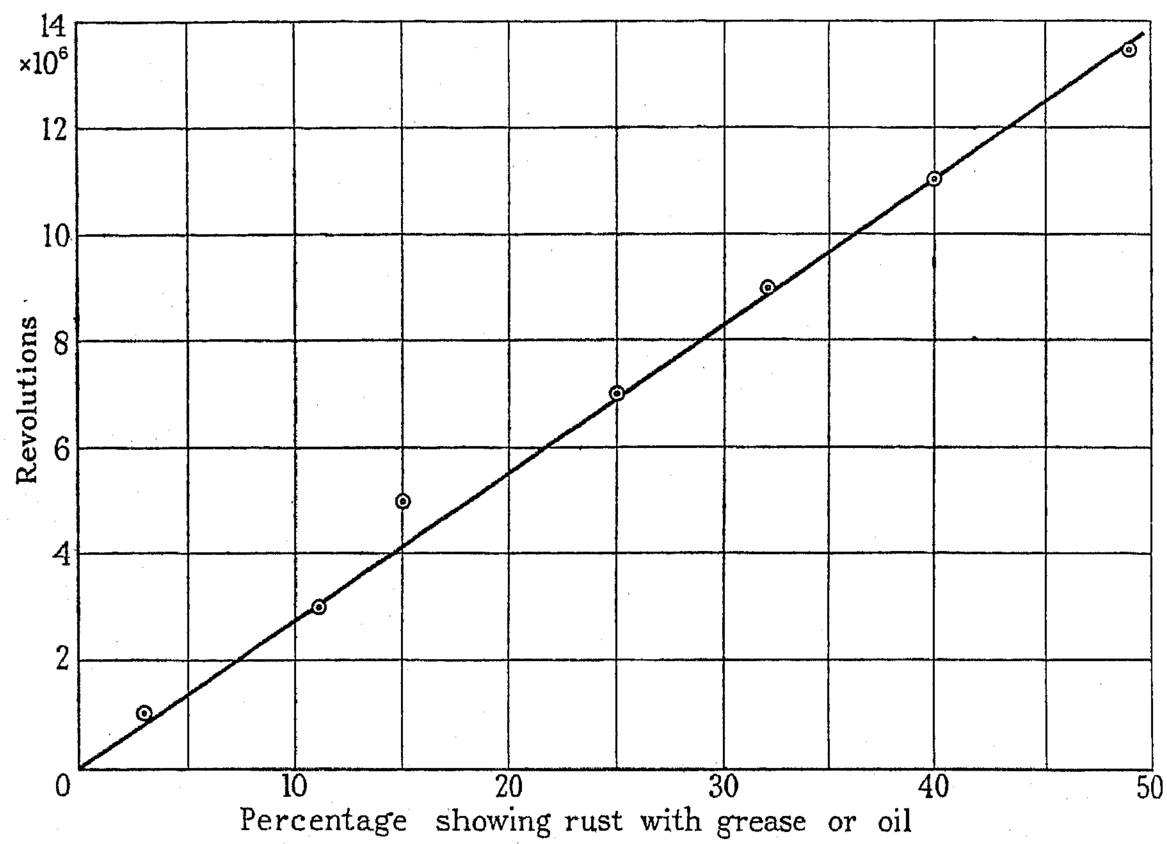


FIG. 1.—Jewel analysis, based on 4 315 jewels examined.

Fig. 5 gives the results of tests on the same rusty jewels and pivots, with a 27-gramme rotor in place of the 16-gramme one. It is clear that there is a considerable increase in friction on account of the additional weight. The rust and grease were removed and further tests were carried out, the differences being plotted between the cleaned pivots and jewels and the new pivots and jewels. These results are given in Figs. 6(*a*) and 7(*a*) for the 16-g and 27-g rotors respectively. The differences due to cleaning are shown in Figs. 6(*b*) and 7(*b*). It should be mentioned that the torque values on the heavy rotor and the light rotor were the same.

The above results point to the existence of a specific factor which determines the wear on the pivots and

TABLE 1.

Number of revolutions, in millions	0–2	2–4	4–6	6–8	8–10	10–12	12–15
Total number of jewels	2 128	934	566	368	175	97	47
Number of jewels with no rust	2 063	832	481	275	119	58	24
Number of jewels with rust	65	102	85	93	56	39	23
Percentage of rusted jewels	3	11	15	25	32	40	49

FIG. 2.—Condition of jewel after 9 million revolutions. Clean grease.

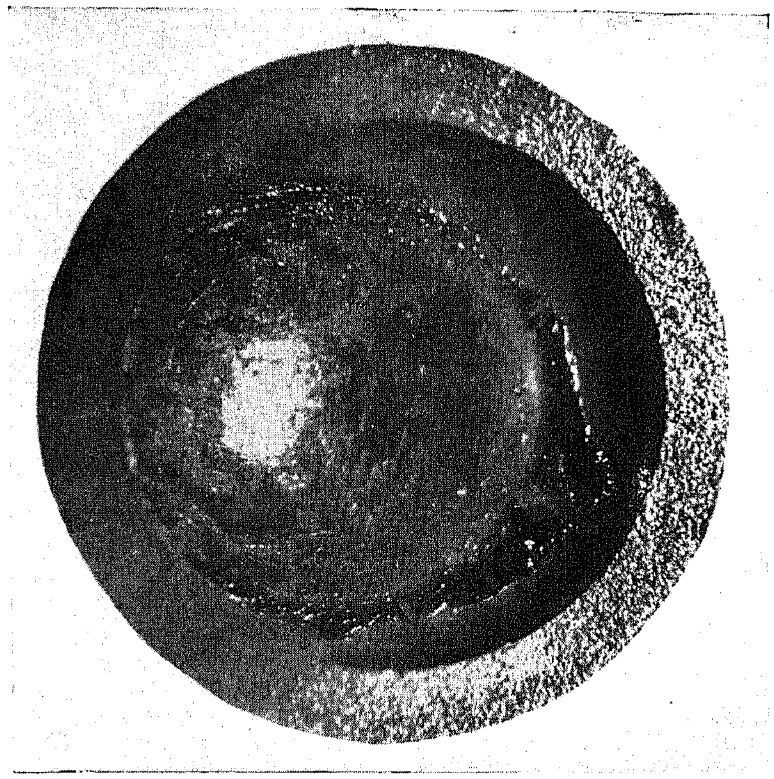


FIG. 3.—Condition of jewel after 9 million revolutions. Rusty grease.

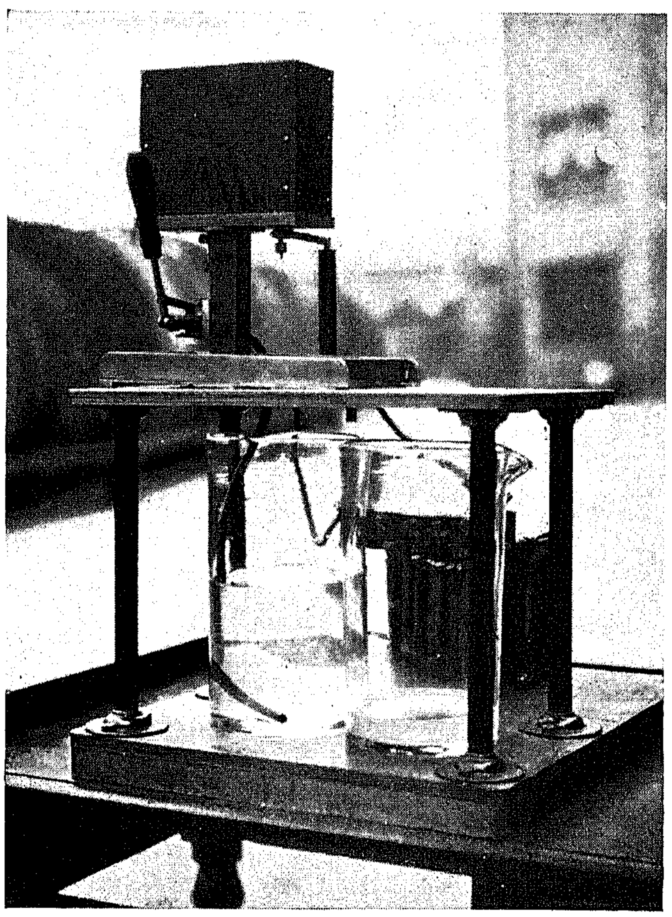


FIG. 11.

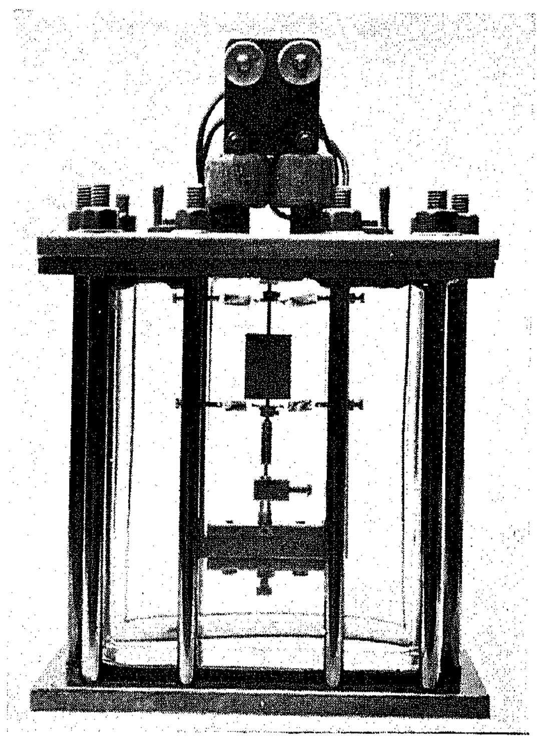


FIG. 22.—Impact test apparatus.

Plate 2.

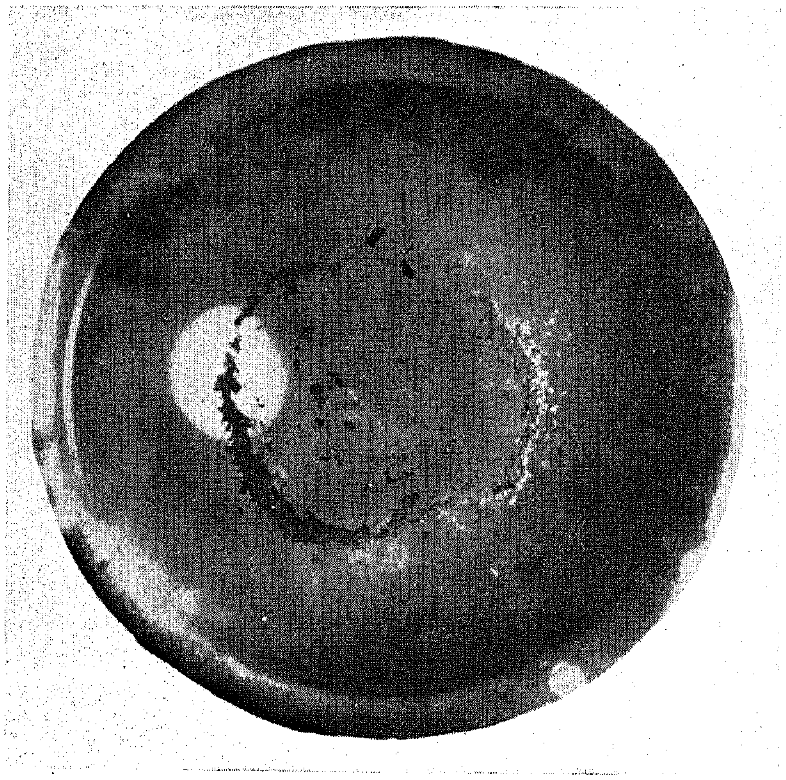


FIG. 25.—Rust produced by first experiment in nitrogen.

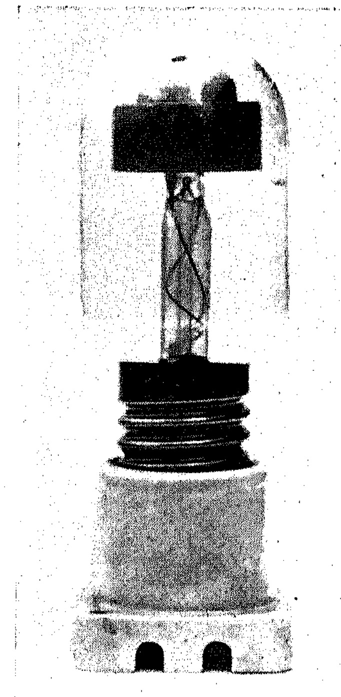


FIG. 26.—Rotating unit in sealed bulb.

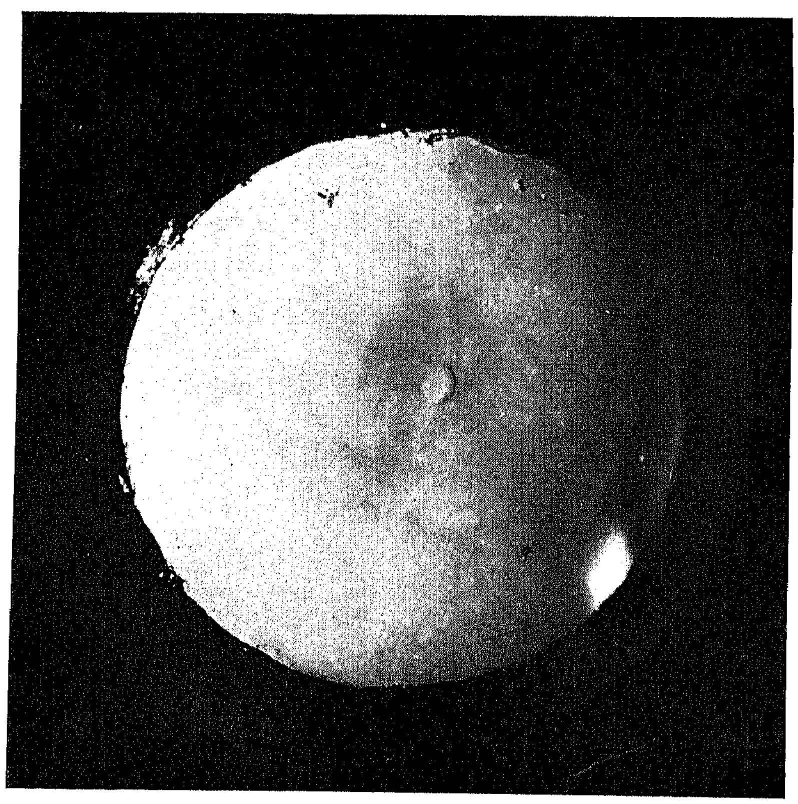


FIG. A. [See Mr. Ockenden's remarks (page 774).]

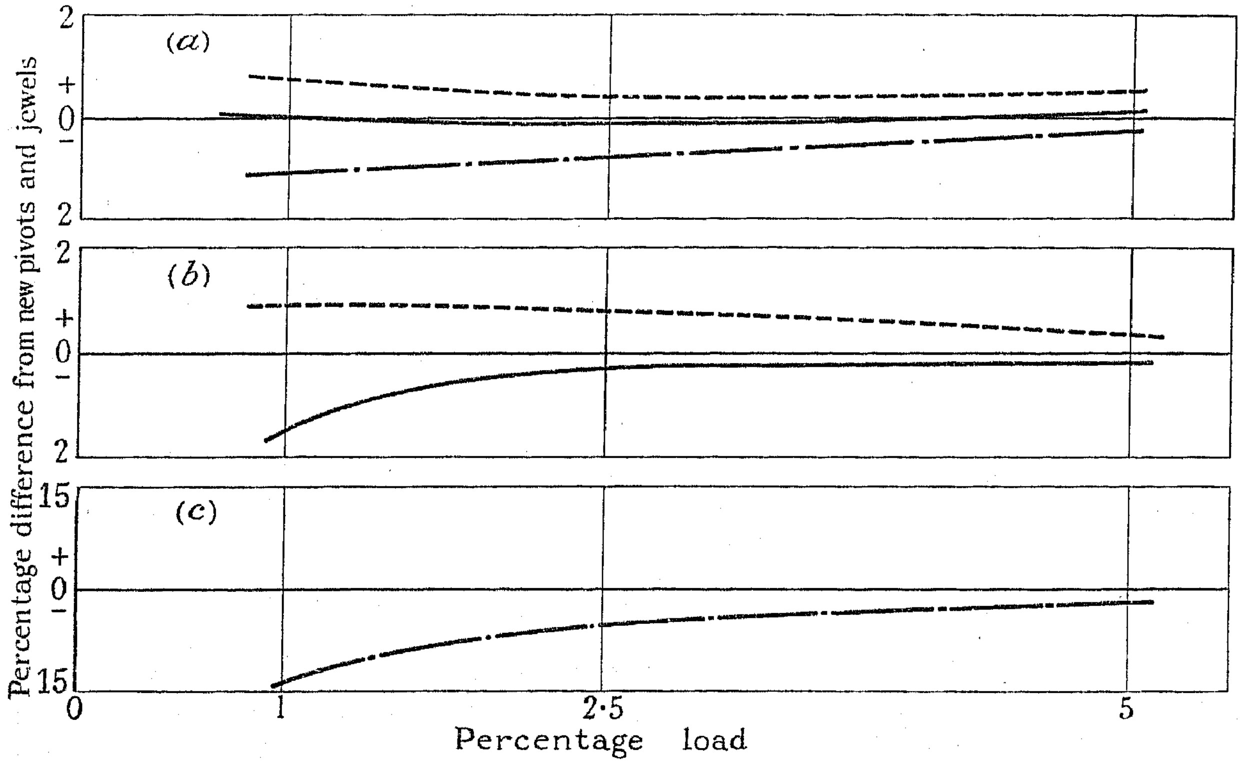


FIG. 4.—Friction tests on pivots and jewels as received from service. Light rotor (16 g).

(a) Clean grease.
(b) Rusty grease.
(c) Rusty grease.

------ Fast limit.
——— Average.
—·— Slow limit.

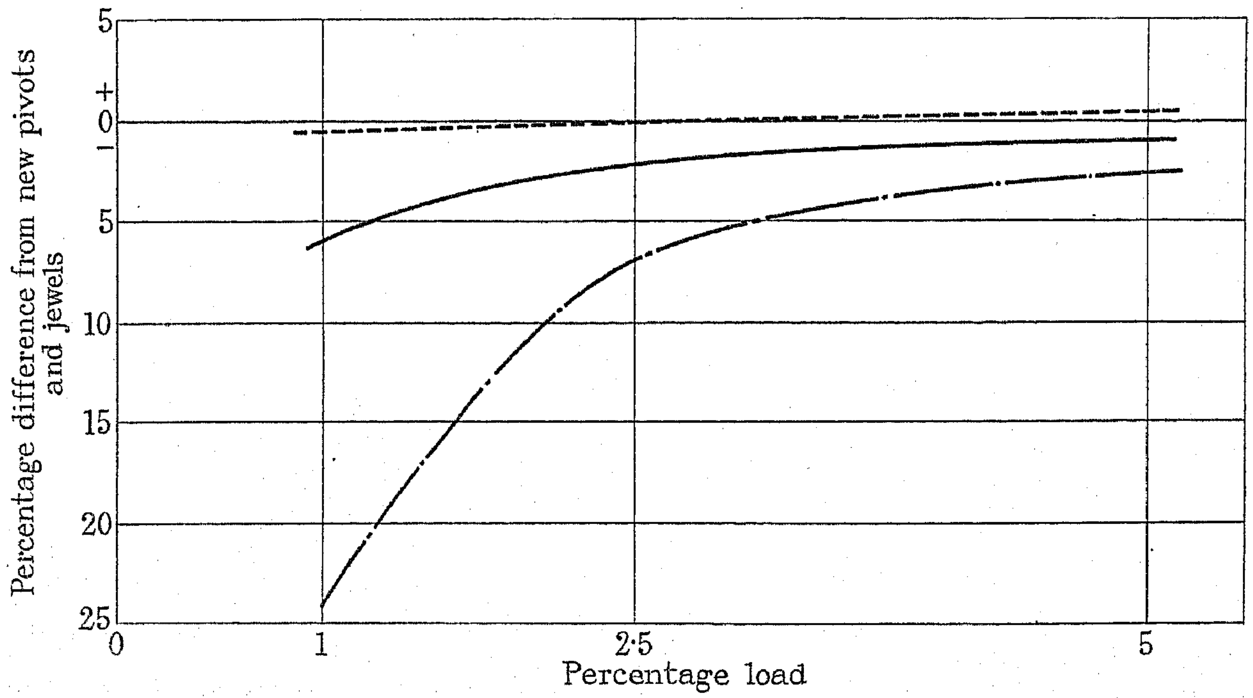


FIG. 5.—Friction tests on pivots and jewels as received from service. Weight of rotor 27 g. Rusty grease.

------ Fast limit. ——— Average. —·— Slow limit.

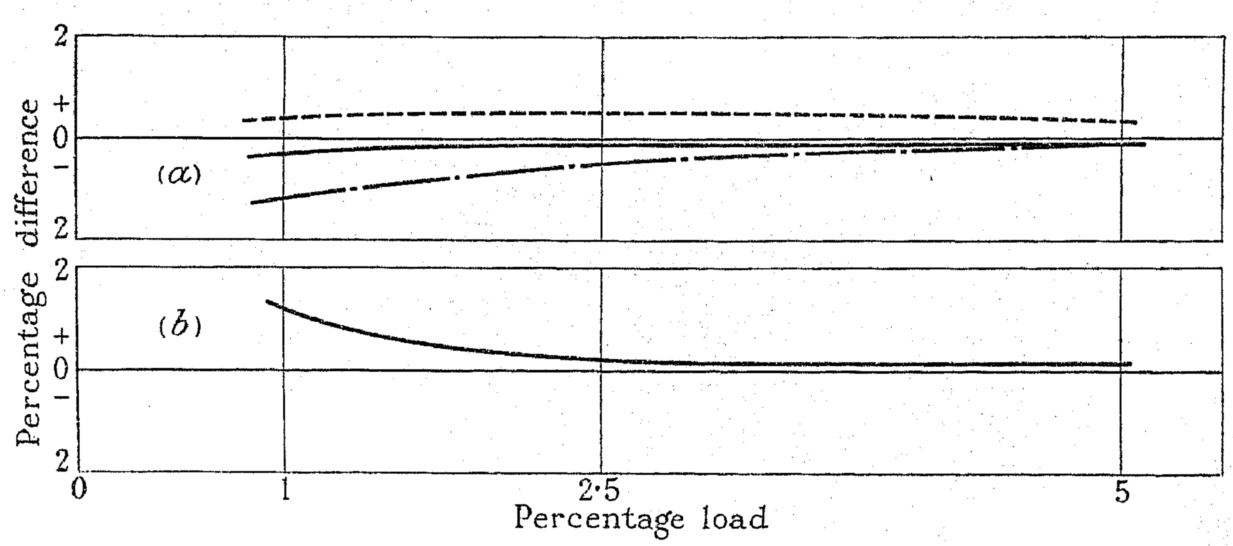


FIG. 6.—Friction tests on pivots and jewels as received from service, after cleaning. Weight of rotor 16 g.

(a) Difference from new pivots and jewels.
(b) Difference due to cleaning.

------ Fast limit.
——— Average.
—·— Slow limit.

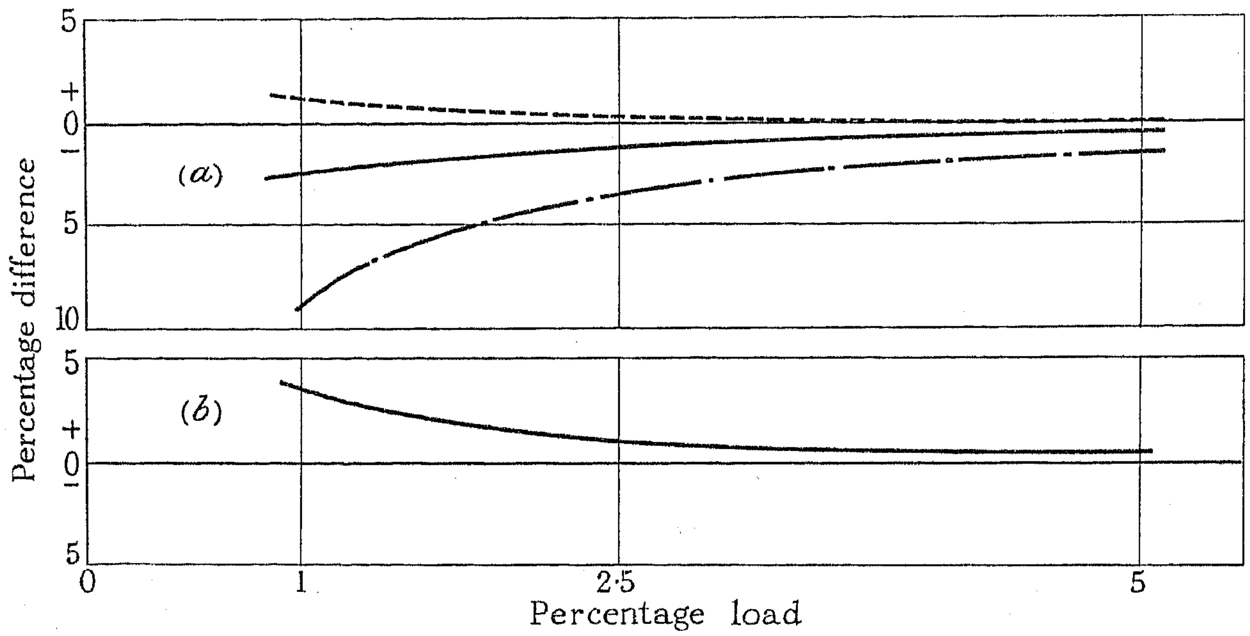


FIG. 7.—Friction tests on pivots and jewels as received from service, after cleaning. Weight of rotor 27 g.

(a) Difference from new pivots and jewels.
(b) Difference due to cleaning.

------ Fast limit.
——— Average.
—·— Slow limit.

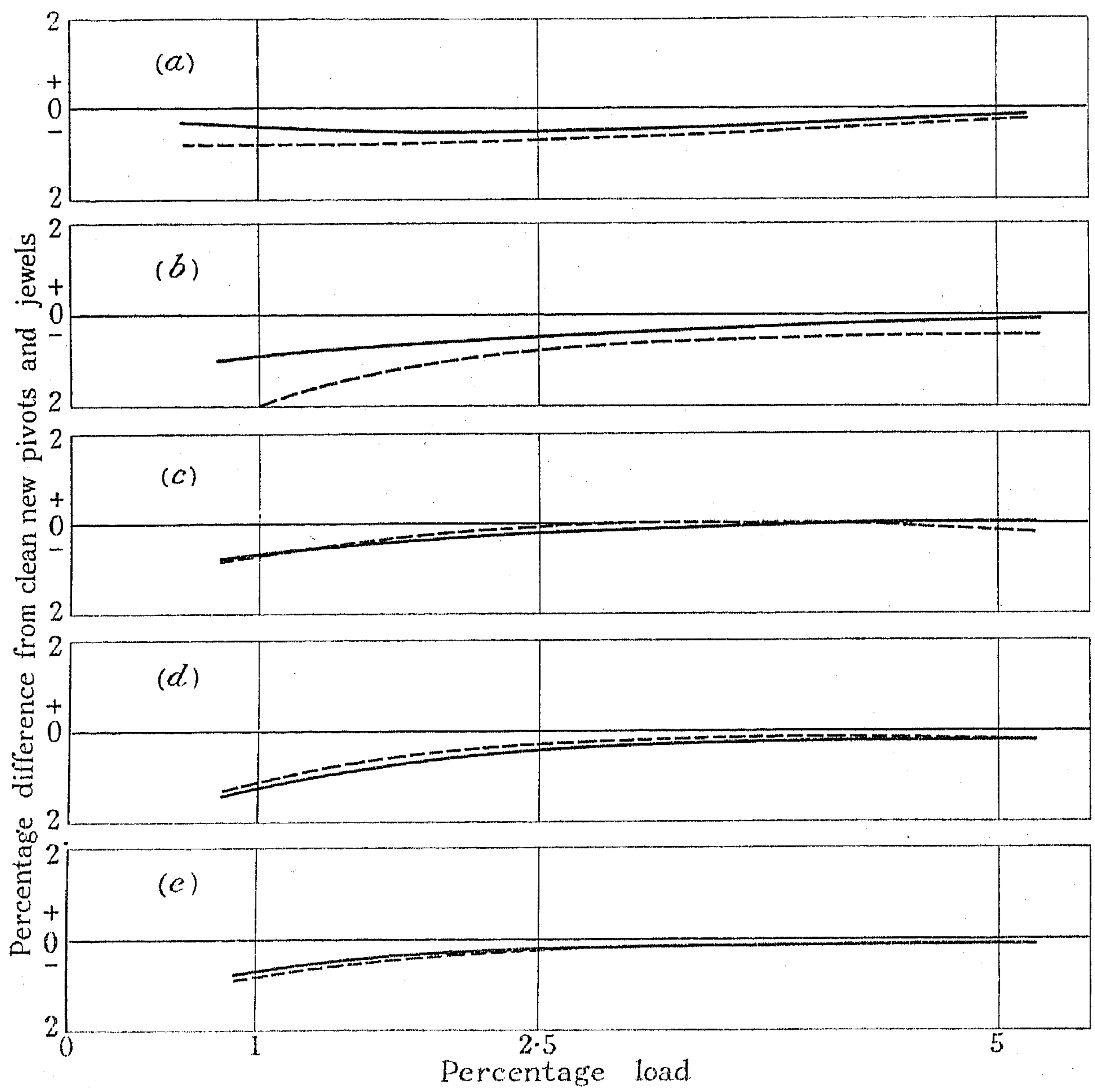


FIG. 8.—Friction tests on new pivot and jewel, using lubricants with and without added abrasives.

(a) Vaseline.
(b) Thick grease.
(c) Resin oil.
(d) Gummed linseed oil.
(e) Resin oil and rust.

------ 27-g rotor.
——— 16-g rotor.

jewels, even when oil is present. The experimental data obtained with oiled jewels show that their performance is at least 30 times better than that of dry. The results of experiments at the National Physical Laboratory* indicated that, for dry jewels, in the best case the friction increased above 10 dyne-cm after $1\frac{1}{2}$ million revolutions. This means that, for a meter having a torque of 5 g-cm (i.e. about 5 000 dyne-cm), an increase in friction of 10 dyne-cm would give a 4 per cent error at $\frac{1}{20}$ load. The results obtained by the author show that if a petroleum-base oil is used, even when the application of a non-creepage solution such as epilame is dispensed with, the errors down to 1 per cent load are not large, despite the fact that the jewels and pivots may be rusty and greasy. The grease and oil tends to keep a great majority of the rust debris off the running surfaces of the pivot and jewel.

(2) Tests on New and Worn Pivots and Jewels, with Various Lubricants and Abrasives.

It was felt that a little more information was required on the effect of different lubricants and abrasives, either alone or in combination. A set of tests was therefore carried out on new pivots and jewels using the following lubricants and abrasives: vaseline, thick grease, resin oil, gummed linseed oil, and resin oil mixed with rust. The results, shown in Fig. 8, indicate that the percentage differences from dry new pivots and jewels are very small. This is not what one would have expected. The rust mixed with the resin oil was commercial ferric oxide, in the proportion of 1 part in 50 by volume. The gummed linseed oil and the resin oils were used in an attempt to produce the same effect as that obtained in the case of a fish oil with time.

Further tests were carried out with two pivots and jewels which had shown more than normal signs of rusty grease. The first pivot and jewel were tested with resin oil, gummed linseed oil, and resin oil plus rust, using first a 16-g and then a 27-g rotor, both having the same full-load torque. The results of these tests are shown in Fig. 9, and it is interesting to compare them with those for the new pivots and jewels shown in the previous curves, bearing in mind that the scale ratio is 2 : 5. Taking, for instance, the resin-oil curve, it will be seen that the error in Fig. 9 is practically $2\frac{1}{2}$ times as great as that in Fig. 8; in the case of the gummed linseed oil the ratio is very much greater, being in the neighbourhood of 10 : 1. The roughened surface of the jewel apparently produces a much greater cohesive drag than the well-polished surfaces. In the case of the resin oil and rust the ratio seems to be in the neighbourhood of 5 times, and the weight appears to be having an effect.

The second lot of tests in this series were made with the jewel shown in Fig. 4(*c*). This particular jewel had

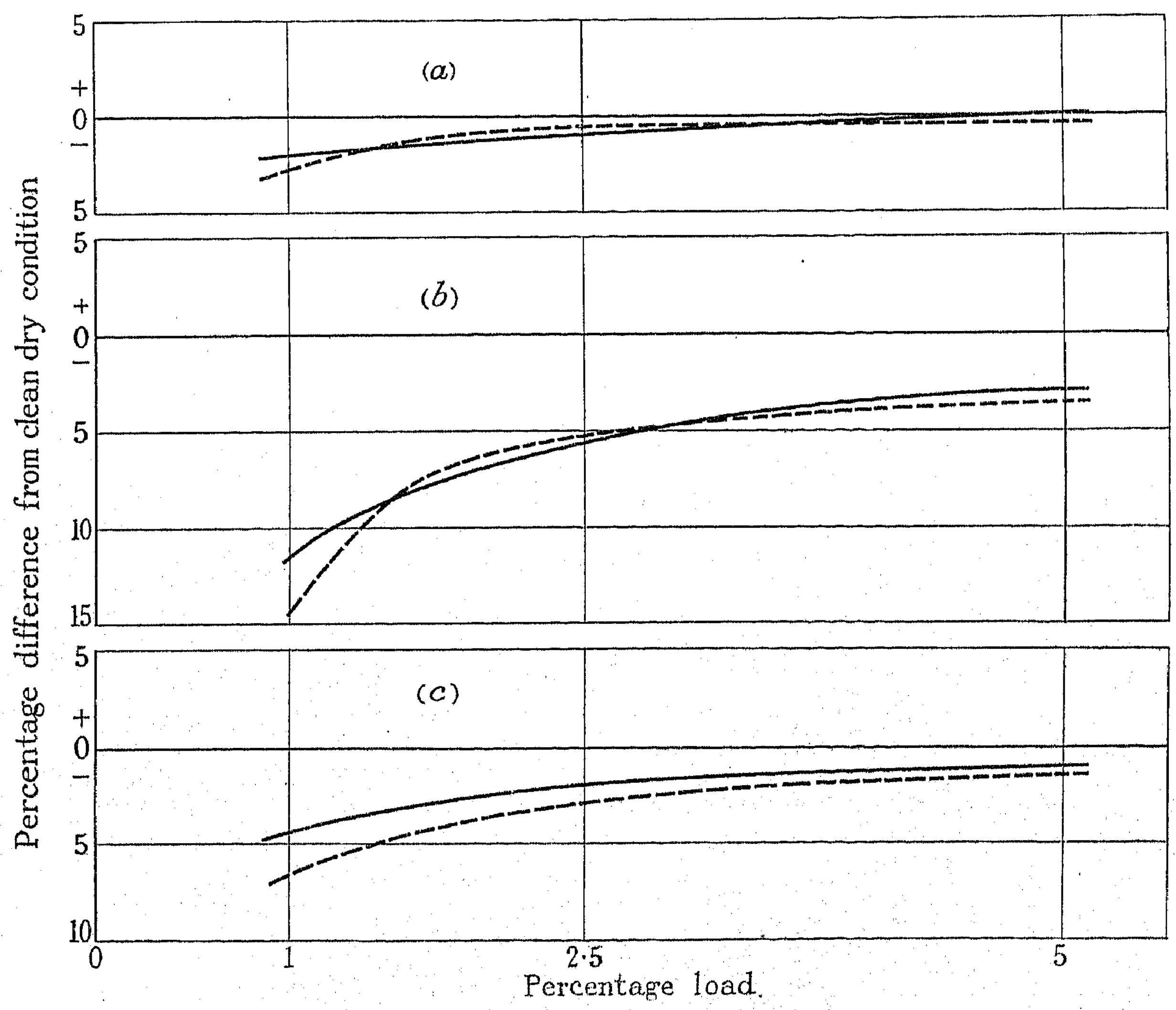


Fig. 9.—Friction tests on pivots and jewels as received from service, using lubricants with and without added abrasives.

(*a*) Resin oil.
(*b*) Gummed linseed oil.
(*c*) Resin oil and rust (1 in 50 by volume).

- - - - - - 27-g rotor.
———— 16-g rotor.

* *Collected Researches of the National Physical Laboratory*, 1931, vol. 24, p. 50.

a wear ring and an abrasion in the centre, and the pivot also showed wear rings. The following lubricants and abrasives were used in this case, the differences again being shown as compared with new pivots and jewels: (*a*) vaseline; (*b*) vaseline and rust, 1 in 50 by volume; (*c*) vaseline and rust, 1 in 20 by volume; (*d*) Sangamo oil and rust (1 in 50 by volume), after running for 1 hour at 20 per cent load; (*e*) Sangamo oil and rust (1 in 50 by volume), after settling for 17 hours; (*f*) dry rust. These results are shown in Fig. 10.

The following conclusions can be drawn from the foregoing tests. First, whereas gumming of the oil has very little effect on a good pivot and jewel, where it is associated with rust it produces extremely bad results. Second, a semi-gummy oil such as resin oil produces very little effect of itself, but when associated with rust or debris it causes fairly large errors. The errors produced by dry rust, particularly where there is any wear on the pivot or jewel, are very serious.

A peculiar instance of the effect of rust on oiled jewels has been observed where periodic cleaning and oiling of jewels is carried out on constant-speed motors which complete 30 million revolutions per annum. If the oil is of low viscosity the rust settles over the bottom of the jewel cup, leaving the oil perfectly clear. It was anticipated that this effect would produce serious errors in meters running at lower speeds, and consequently tests (*d*) and (*e*) mentioned above were carried out. These tests proved that the errors on a constant-speed motor would not be appreciable, but that, on an ordinary house service meter where the speed may remain low for a considerable period, the errors are accentuated.

It is apparent from these results that a good-quality grease of high stability is preferable to a low-viscosity oil. The examinations conducted by the author prove that where a large quantity of grease is present there can also be a large amount of wear and rust production, without the rust being apparent. The rust may be invisible owing to its assimilation within the body of the grease.

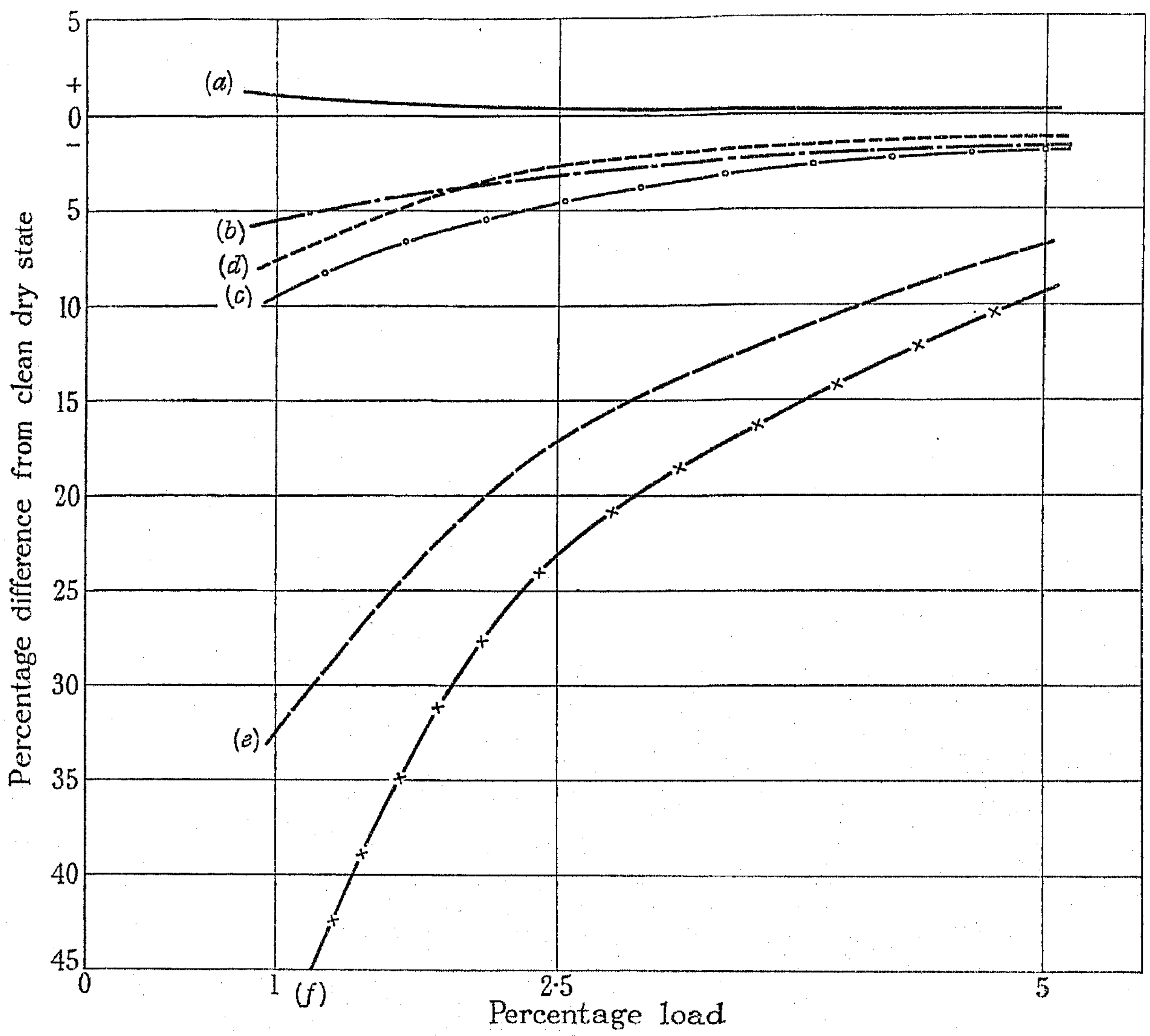


FIG. 10.—Friction tests on a worn pivot and jewel, using various lubricants and abrasives. Weight of rotor 16 g.

(*a*) ——— Vaseline.

(*b*) —·— Vaseline and rust (1 in 50 by volume).

(*c*) —o— Vaseline and rust (1 in 20 by volume).

(*d*) ------ Sangamo oil and rust (1 in 50 by volume), after running for 1 hour at 20 per cent load.

(*e*) — — Sangamo oil and rust (1 in 50 by volume), after standing for 17 hours.

(*f*) —x—x Dry rust.

Summing up Sections (1) and (2), it would appear that oiled jewels are far superior to unoiled, but that even when oiled or greasy jewels are employed the rust is the major cause of the error.

(3) CLEANING OF JEWELS AND PIVOTS.

It is absolutely essential to get rid of debris in any form, particularly where dry pivots and jewels are being

tested, and one of the great difficulties to be overcome is that of the cleaning of jewels and pivots. Fig. 11 (see Plate 1) shows the apparatus used by the North Metropolitan Electric Power Supply Co. for cleaning jewels by means of steam.

The boiler consists of a length of nickel-silver tube, $\frac{1}{8}$ in. bore, $\frac{5}{32}$ in. outside diameter, made up into a coil having a diameter of approximately 4 in. Between each convolution there is a mica separator, the whole being clamped together by a single bolt passed through the centre. The length of tube used is about 12 ft. A small hand pump is fitted to one end of the boiler, and a small detachable nozzle to the other. The nozzle, which is mounted in a brass holder, is a nickel capillary tube similar to those used in recorder syphon pens. The inlet end of the boiler is provided with an atomizing injector, the whole unit being suitably lagged. At each end of the nickel-silver tube, connection is made to the secondary of a low-voltage transformer via a short piece of nichrome heater ribbon; the reason for inserting this ribbon, particularly at the nozzle end, is to prevent condensation. It has been found essential to use only filtered distilled water. Nickel-silver tubing was used after tubes of stainless steel and ordinary steel had been tried. In the latter two cases it was found difficult to get the bore of the tube clean and free from scale. The apparatus has proved most effective; not only does it render the surface of new jewels and pivots perfectly clean, but it also cleans in a few seconds jewels which have been returned from service with greasy surfaces.

When greasy jewels are being cleaned the boiler is first primed and saturated steam is used, the final polish being given by means of superheated steam. A little practice in the use of the apparatus is necessary if perfect results are to be obtained.

(4) Oil-Film Tests.

A description will now be given of a series of experiments which were conducted in an attempt to find out the nature of the protection afforded to pivots and jewels by oil or grease. Some writers doubt the existence of an oil film at the high pressures under which the pivot and jewel work. The theory that the author has always entertained is that whereas with a stationary pivot and jewel it is quite possible that the film may be fractured, this condition cannot persist when the pivot is moved. In the latter case the action may be regarded rather in the light of Michell's thrust, the pivot being considered to "skate" over a film of oil. The following experiment was made to test this theory.

A ball-ended steel pivot was fixed to the beam of an ordinary chemical balance. Directly above this pivot was fixed a flat, polished tungsten plate. By adding weights to one of the pans it was possible to vary the pressure between the ball pivot and the tungsten plate, and by moving the beam lifting-arm it was possible to produce a sliding action between the pivot and the plate. The electrical connections are shown in Fig. 12. By adjusting the various resistances it was possible to vary the voltage across the contacts. Preliminary tests with both dry and lubricated surfaces showed that within the range of 1 to 6 millivolts the voltage across the contact had only a secondary effect upon the results; the value of 4 millivolts was adopted for comparison between the various lubricants. The experiment consisted of first proving the stability of the dry contact, by moving the pivot across the surface of the tungsten plate and noting whether the galvanometer reading remained at zero. It was found difficult to ensure that this condition was established, and various methods for cleaning the surfaces were tried. The best method appeared to be cleaning with carbon tetrachloride.*

Among the various lubricants tried were: (*a*) A highly distilled mineral oil, normally used by the author's undertaking in their own meters; (*b*) a medicinal paraffin of a higher viscosity; (*c*) white vaseline.

The results of a large number of experiments may be summarized as follows. With all the lubricants, using weights up to 25 and 30 g and with the pivot stationary, partial metallic contact appeared to be made, but contact was definitely broken when the pivot was moved across the surface of the tungsten plate. Of all the lubricants used, the vaseline seemed to stand up to the greatest

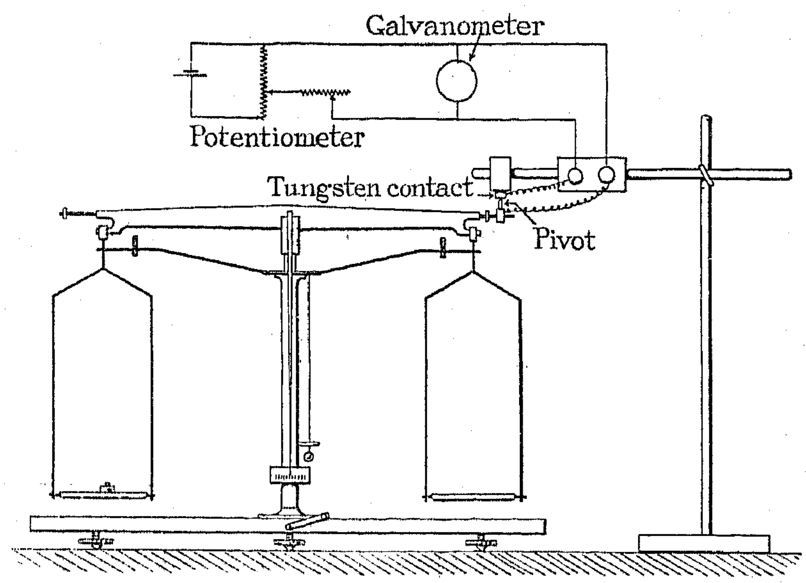


Fig. 12.—Oil-film test apparatus.

weight. Momentary contact was occasionally made when travelling across the surface.

More refined tests of this character might lead to interesting results from the point of view of the ability of oil films to sustain heavy weights when bearings of the form of the ordinary pivot and jewel are employed.

Before leaving this Section, it may be of interest to mention the great difficulty that we have found in getting rid of the last traces of oil from metallic and jewel surfaces. As the slightest trace of oil will falsify the results obtained with presumably dry pivots and jewels, it is very necessary to ensure the certainty of the cleaning.

(5) Tests on Various Pivot Materials, Oiled and Dry.

Turning now to the question of pivot materials, a number of tests have been carried out on 16-g and 27-g movements having a torque at full load of 5 g-cm, the rotors being run at 25 r.p.m. Some of the bearings were run dry and some lubricated. The following list gives the various pivot-jewel combinations employed; it

* The author now believes that a final cleaning with steam, by the method adopted for pivots and jewels, would have been better.

will be noticed that sapphire jewels were used throughout.

(i) Sapphire-steel, lubricated with oildag, 16-g rotor; results as in Fig. 13.

(iv) Sapphire-duralumin, (*a*) dry, (*b*) oiled; 16-g rotor; results as in Fig. 16.

(v) Sapphire-aluminium, (*a*) dry, (*b*) oiled; 16-g rotor; results as in Fig. 17.

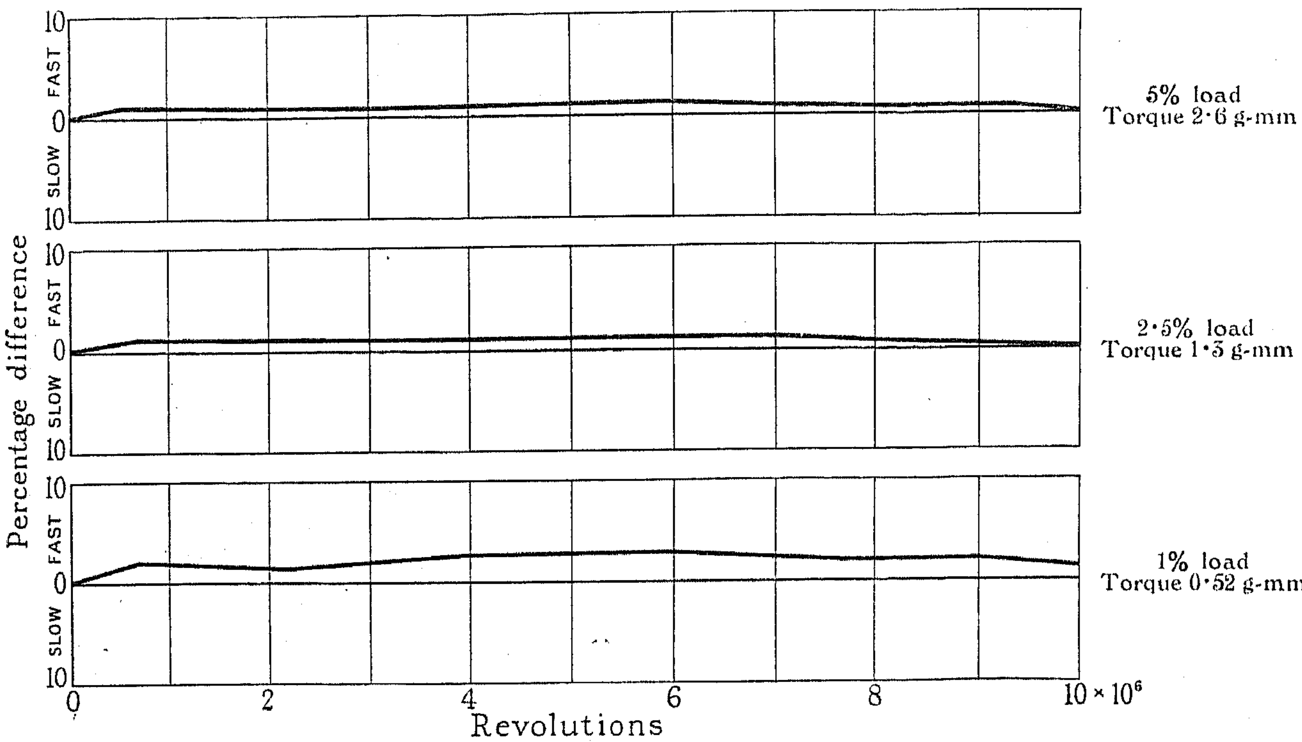


FIG. 13.—Sapphire-steel combination, lubricated with oildag. Weight of rotor 16 g.

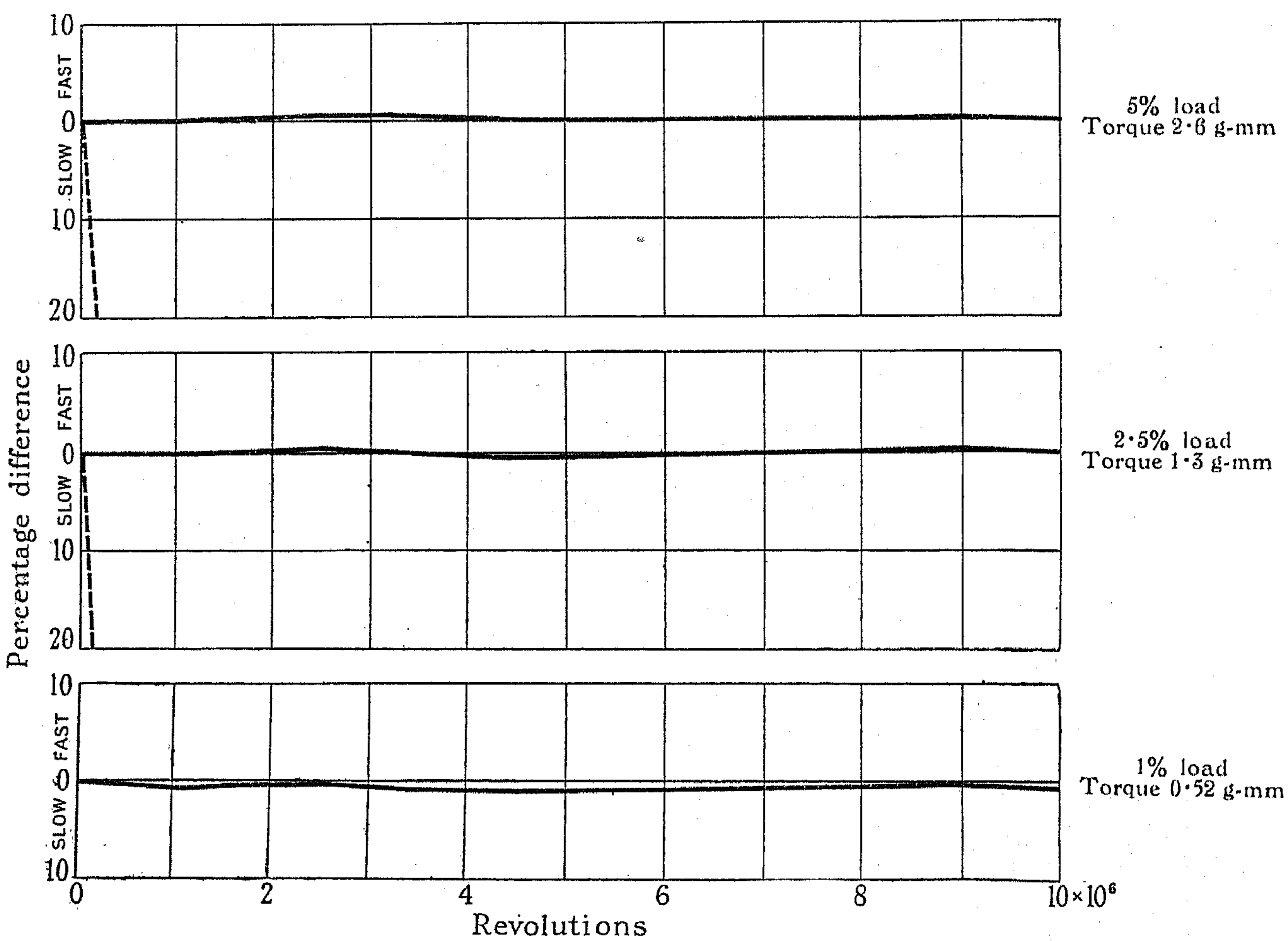


FIG. 14.—Sapphire-stellite combination. Weight of rotor 16 g.

------ Dry.
——— Oiled.

(ii) Sapphire-stellite, (*a*) dry, (*b*) oiled; 16-g rotor; results as in Fig. 14.

(iii) Sapphire-sapphire, dry, 16-g rotor; results as in Fig. 15.

(vi) Sapphire-phosphor bronze, (*a*) dry, (*b*) oiled; 16-g rotor; results as in Fig. 18.

(vii) Sapphire-tungsten, dry, 16-g rotor; results as in Fig. 19.

(viii) Sapphire-platinum-iridium, dry, 16-g rotor; results as in Fig. 20.

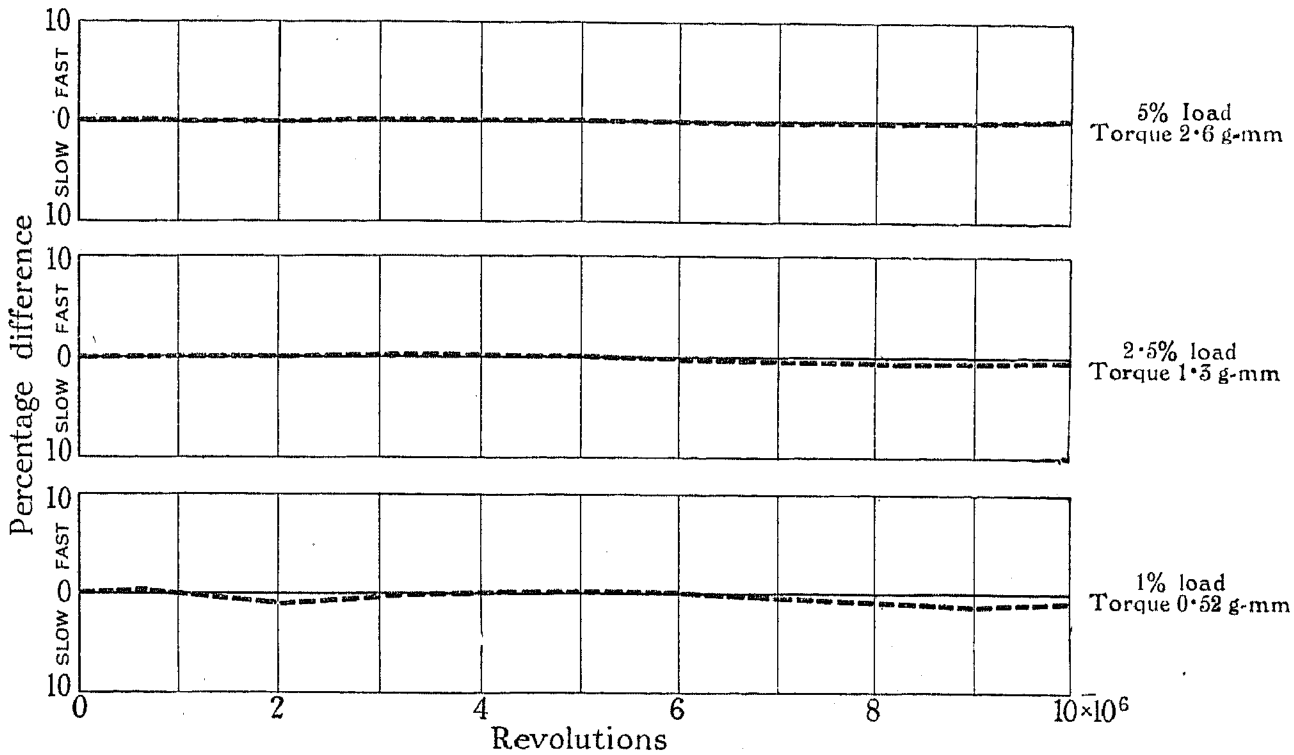


FIG. 15.—Sapphire-sapphire combination (dry). Weight of rotor 16 g.

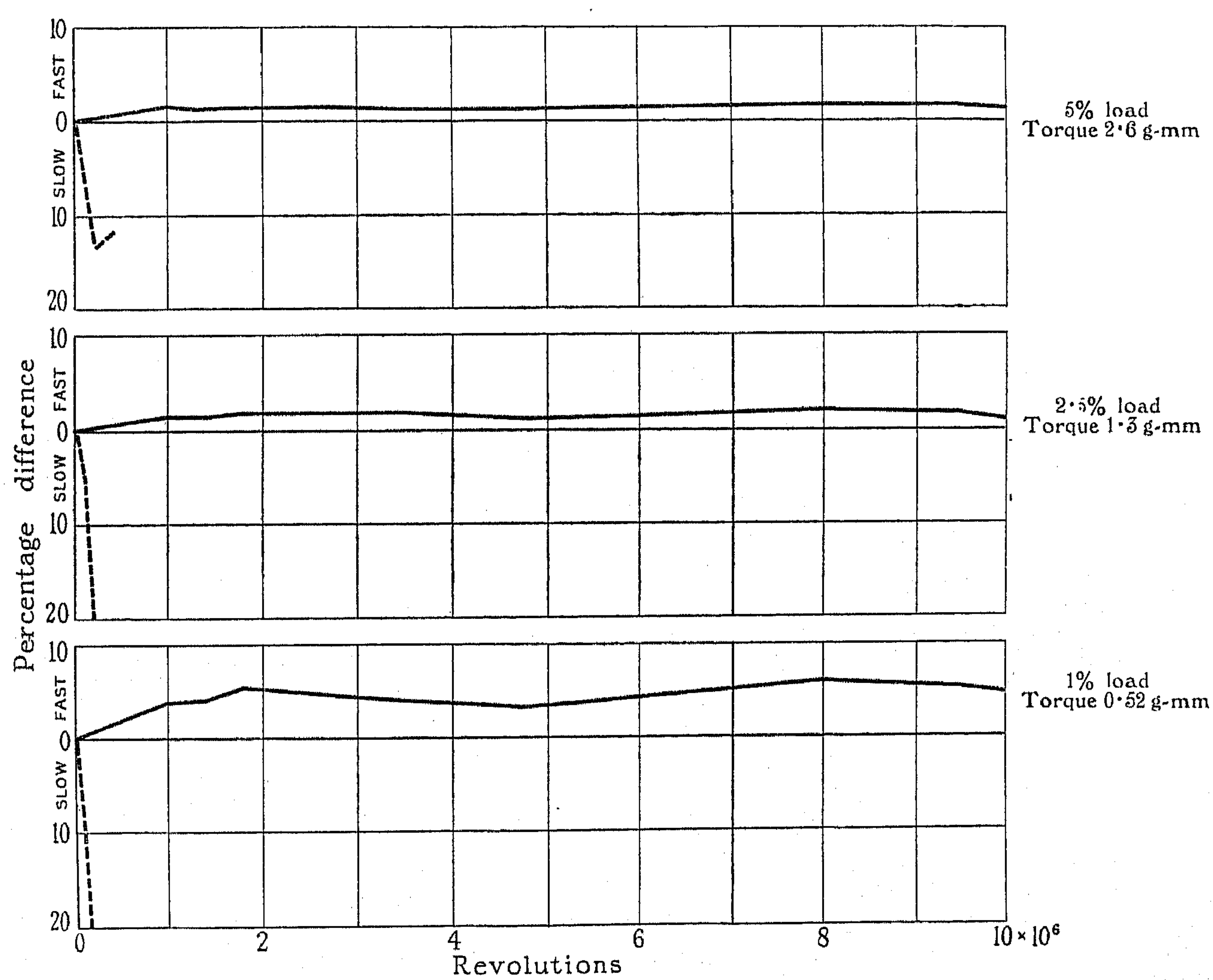


FIG. 16.—Sapphire-duralumin combination. Weight of rotor 16 g.

------ Dry.
——— Oiled.

(ix) Sapphire-platinum, (a) 16-g rotor, (b) 27-g rotor; dry; results as in Fig. 21.

The results, plotted in Figs. 13 to 21, are given for three loads only: 5 per cent, equivalent to a torque of 2·5 g-mm; $2\frac{1}{2}$ per cent, equivalent to a torque of 1·25 g-mm; and 1 per cent, equivalent to a torque of 0·5 g-mm. The errors stated are the differences from the initial errors. The latter are only slightly different from those of the sapphire-steel combination.

Particularly consistent results up to 10 million revolu-

tions are shown by (i), the sapphire-steel combination lubricated with oildag. This lubricant, which consists of colloidal graphite in suspension in oil, is referred to in the following terms by Mr. H. Shaw.* "If colloidal graphite is added to the lubricant a very fine film of graphite will form on all the lubricated surfaces, which although of negligible thickness is so tenacious that it cannot be removed by ordinary cleaners, but only by abrasion. This graphoid film, as it is called, has the peculiar property of being more readily 'wet' by the lubricant than is the metal of the bearing. If the graphoid film is readily wet, it is obvious that the lubricant will rapidly spread over it. This means that if the oil film should be broken by the imposition of an excessive load the lubricant will rapidly spread and re-form a complete oil film."

The results obtained with the various combinations will now be discussed in detail.

(i) *Sapphire-steel.*—Microscopical examination† after 9·5 million revolutions showed that the oil on the jewel was separating from the graphite, and that there were no signs of wear on the pivot.

(ii) *Sapphire-stellite.*—The test on this combination is of peculiar interest as stellite is extremely hard. As will be observed from Fig. 14, when run dry it appears to be absolutely useless as a pivot, whereas when oiled it gives remarkably consistent results. Microscopical examination of the dry bearing after 5 million revolutions revealed that the jewel was worn in circles and the pivot was scored in circles, both pivot and jewel being coated with a large quantity of white debris. Microscopical examination of the oiled bearing after $14\frac{1}{2}$ million revolutions showed no definite change in the jewel, whereas on the pivot two running circles—of 0·007 in. and 0·010 in. diameter respectively—had been worn.

(iii) *Sapphire-sapphire.*—Microscopical examination after $9\frac{1}{2}$ million revolutions showed a small quantity of white debris on the jewel and pivot. This pair is still giving extremely good results, but more investigation is

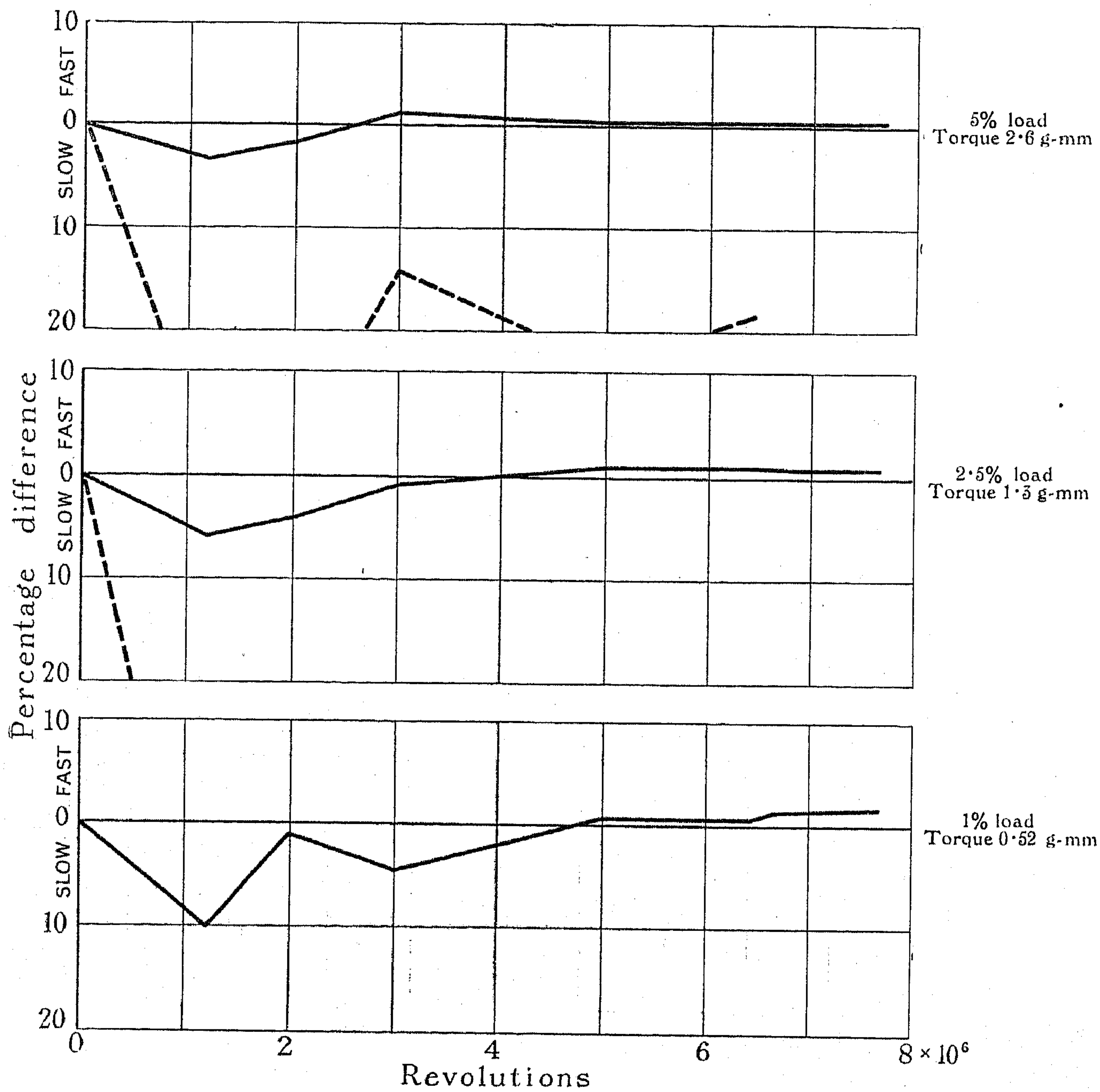


FIG. 17.—Sapphire-aluminium combination. Weight of rotor 16 g.

------ Dry.
——— Oiled.

* *Machinist*, 17th September, 1932.

† Throughout these tests a magnification of about 70 was used for viewing the pivots and jewels.

needed before a decision is given as to whether the combination is suitable for bearings.

(iv) *Sapphire-duralumin.*—When run dry the duralumin pivot appears to be of no practical use, whereas when oiled it gives remarkably consistent results. Microscopical examination of the dry bearing after 400 000 revolutions showed that the jewel was coated with a large quantity of debris, some light and some dark grey in colour, while the pivot was covered with black debris. Examination of the oiled bearing under the respective running circles is approximately equal to the ratio of the hardness figures for the two materials. At the end of the 300 000 revolutions the jewel and the duralumin pivot were cleaned and fresh oil was inserted; since then no changes have occurred in the running-circle diameter, nor has the oil become discoloured. It has been observed that the running circle of the pivot has a matt appearance, instead of the usual high polish.

(v) *Sapphire-aluminium.*—The results for the oiled bearing are fairly good; the peculiar dip in the curves,

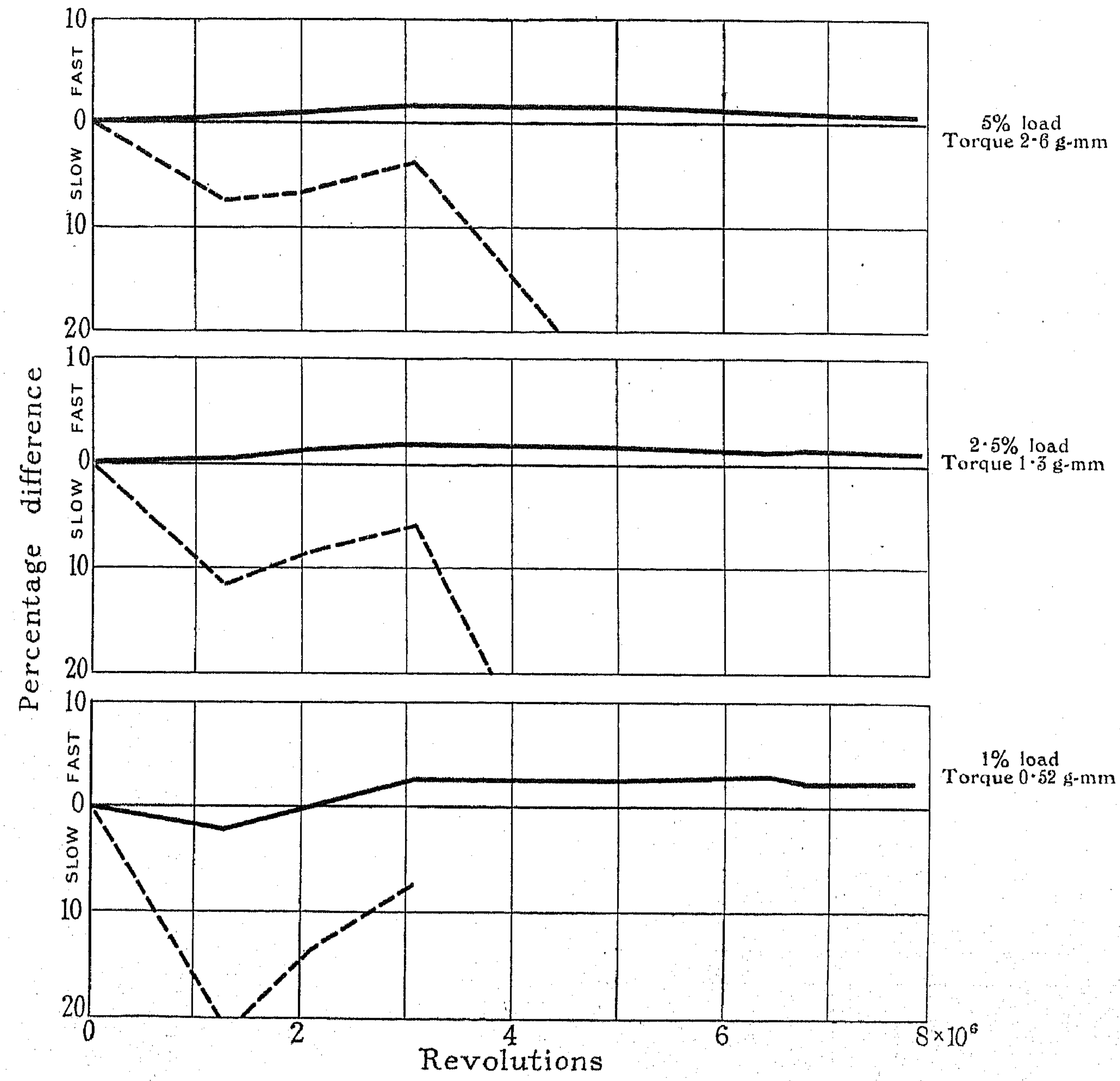


FIG. 18.—Sapphire and phosphor-bronze combination. Weight of rotor 16 g.

------ Dry.
——— Oiled.

the microscope, after 15 million revolutions, showed that the oil on the jewel had been converted to grease, but there was no discoloration. On the pivot, however, there was a yellowish-green tinge to the grease, and a running circle of 0·021 in. diameter. When this pivot was first made it had a radius of 0·025 in., and it was run on a jewel of 0·08 in. radius. When it was first run in the oiled sapphire, the oil was blackened and a running circle was formed of 0·021 in. diameter after 300 000 revolutions. The normal running circle of a steel pivot of the same curvature, with the same weight (16 g), is of about 0·006 in. diameter. The ratio of the areas of which is also shown by other combinations, may have something to do with the stabilization of the radius. The dry bearing appeared to be most unsatisfactory. When examined microscopically after $6\frac{1}{2}$ million revolutions it showed a large quantity of coarse aluminium-coloured debris, the pivot having a running surface of matt appearance.

(vi) *Sapphire and phosphor-bronze.*—A marked difference is apparent between the oiled and the dry bearing, the latter being of no practical value. Microscopical examination of the dry bearing after $6\frac{1}{2}$ million revolutions showed large quantities of yellow debris on the

jewel, and yellow-green debris on the pivot, which was deeply worn in rings. Examination of the oiled bearing after 6 800 000 revolutions showed a film of clean oil on the jewel, with reddish debris at the top of the cup; the pivot was seen to be black on its running circle and

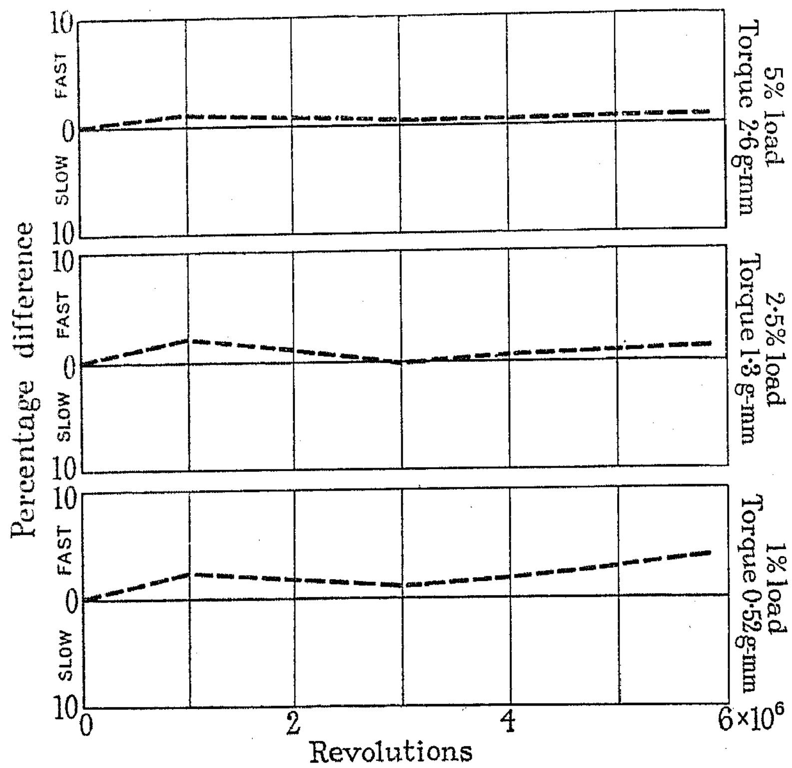


FIG. 19.—Sapphire-tungsten combination (dry). Weight of rotor 16 g.

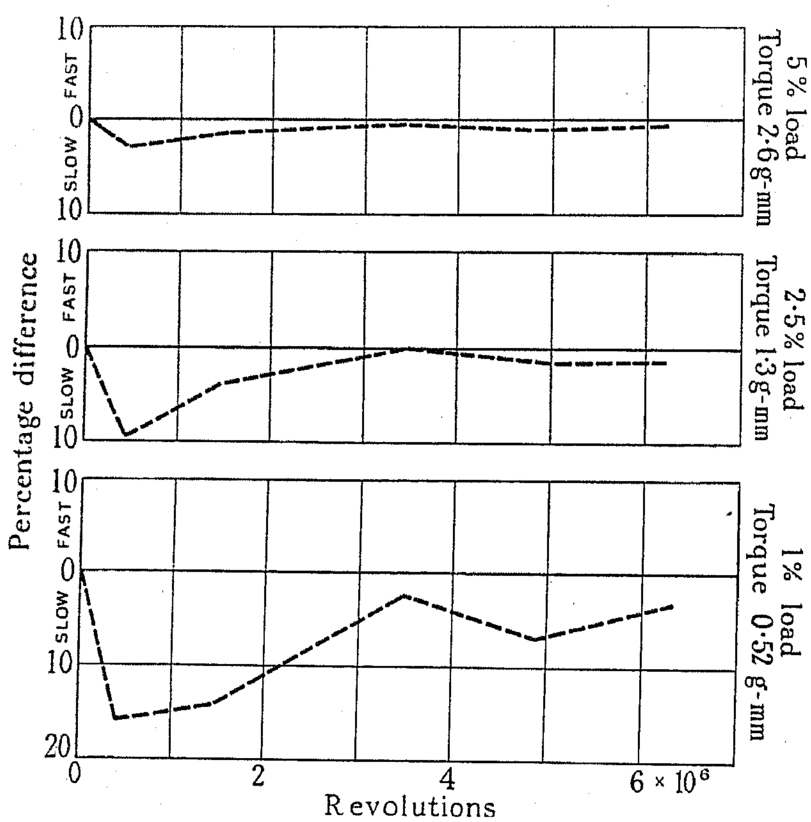


FIG. 20.—Sapphire and platinum-iridium combination (dry). Weight of rotor 16 g.

reddish-coloured on its outer edge, the surface being roughened.

(vii) *Sapphire-tungsten.*—Examination after 5 million revolutions revealed a quantity of fawn-coloured debris of fine texture on both the pivot and the jewel. The production of a fawn-coloured debris by this combination is very interesting, as tungsten is a hard material but yet is almost unaffected by atmospheric conditions. The effect of this debris on the accuracy is negligible; there even appears to be a decrease in the friction.

(viii) *Sapphire and platinum-iridium.*—This combination was chosen because under normal conditions neither platinum nor iridium can be oxidized. It was thought that if non-metallic debris were produced by this bearing it would confirm Mr. Stott's theory that oxygen can be set free from the sapphire under the influence of the large cohesive forces which operate in meter bearings. The Brinnell hardness of the pivot alloy is 237, the figure for iridium being given as between 400 and 500 and

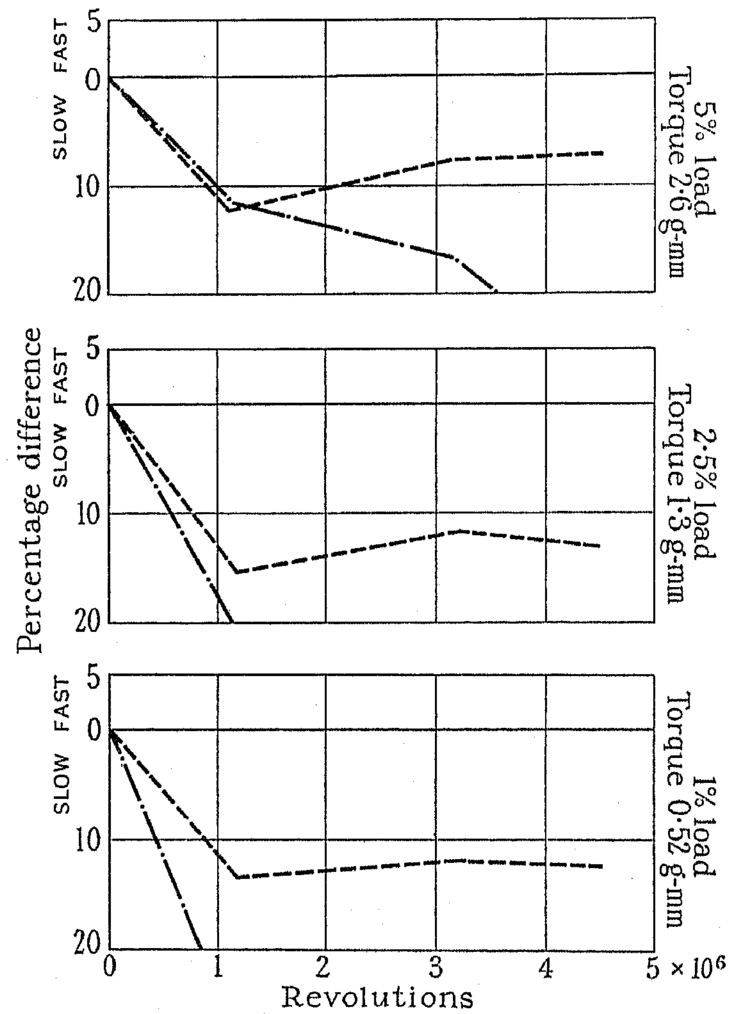


FIG. 21.—Sapphire-platinum combination (dry).

------ 16-g rotor.
—·— 27-g rotor.

that for platinum as 40. It will be observed from Fig. 20 that, as in previous tests, a dip in the curve is obtained within the first 2 million revolutions, but that it subsequently approaches the original condition. As compared with a new sapphire-steel bearing, at the start of the test the sapphire and platinum-iridium combination was 0·1 per cent slower at $\frac{1}{20}$ load, 0·5 per cent slower at $\frac{1}{40}$ load, and 2·2 per cent slower at $\frac{1}{100}$ load. Microscopical examination after 5 million revolutions showed a large quantity of dark fawn debris on the jewel, and a coating of dark fawn debris on the pivot.

(ix) *Sapphire-platinum.*—This test was carried out with the double object of determining the value of platinum as a bearing material and of testing the sapphire-oxygen theory. Rotors of two different weights—16 g and 27 g—were used. A marked difference was observed in the amounts of friction produced by the two weights, and a feature of the results was the recovery of the bear-

ing with the lighter rotor. It may be that the pivot radius (0·025 in.) employed was too small, and that a larger radius—with the possible modification of the jewel radius—would have given different results. With regard to the sapphire-oxygen theory, it is interesting to record that the debris did not consist of metallic platinum. In his experience, extending over many years, of the use of platinum as an anode in electrolysis, the author has never detected any oxidization; this implies that platinum is not attacked even by nascent oxygen. Microscopical examination revealed a large quantity of yellow-white debris on the light-rotor jewel and similar debris on the pivot, which was worn in circles; the heavy-rotor jewel and pivot were shown to be coated with yellowish debris, the pivot being worn in rings.

In the course of several series of tests carried out on a diamond-steel combination in a dry condition, debris having a bright metallic lustre was produced. It differed from the debris noticed on the sapphire-platinum, sapphire and platinum-iridium, or sapphire-tungsten combinations, in being colourless and consisting of particles dotted here and there on the running surface, instead of being heaped around it.

Much more experimental work is required on the lines of the tests described in this Section to enable definite conclusions to be formed. Among the points which seem to stand out from the experiments, however, is the extraordinary effect of oil, even when a soft material like aluminium is used for the pivot. For instance, stellite, a harder material than steel, appears to give very much worse results than the latter when dry. On the other hand, materials of all hardnesses—ranging from aluminium to stellite—give comparatively good results when oiled. Any material having the correct radius to suit its hardness, appears to give good results when lubricated. Of the combinations used for the dry bearings, sapphire-sapphire, sapphire-tungsten, and possibly sapphire and platinum-iridium, would appear to have good possibilities. To determine the true effect of the rate of wear, further tests are required using the various pivot materials mentioned above, in conjunction with jewels having the same orientation of the optic axis.

(6) Impact Tests in Air and in Nitrogen.

The author's experience with sapphire jewels from various sources, including those taken from meters returned from service, has shown one common defect, namely surface cracking. Considerable thought and investigation have been devoted to the elucidation of its cause. Although surface cracks may not be harmful in a jewel when they are well off the running circle, they may be the cause of excessive wear when on it. Many of the jewels taken from returned service meters still have a perfect polish and could be used again but for the presence of surface cracks. In the majority of instances, however, the surface cracks are on the sides of the jewels, which may in some cases be re-issued.

In an attempt to solve the problem, the apparatus shown in Fig. 22 (see Plate 1) was constructed. As will be seen, the movement consists of a spindle upon which is fixed a mass of approximately 16 g. At the bottom end of this spindle is fixed a suitable pivot, and, at the top, a soft iron armature; the whole movement being suspended between four springs. The amount of motion is limited to that normally allowed for the movement in an electricity meter. A clock contactor is used for exciting the small electromagnet fixed on the top of the apparatus, which raises the mass away from the jewel mounted underneath. Impact between the pivot and jewel is made when the circuit is broken, and there are 18 impacts per minute. It is possible, by adjustment of the bottom supports, to arrange for the pivot to strike either on the centre of the cup or on the side of the jewel, as required.

The results of a large number of tests carried out with this apparatus showed that after 30 000 to 40 000 impacts on a dry jewel (impacted on the side) surface cracks were produced. It was also found that surface cracks could more readily be produced if the jewel was tilted so that the direction of impact was at an angle less than 90° to the base plane of the jewel. Rust could be formed on most jewels within the above number of impacts.

In some experiments with the jewel and pivot lubricated one particular jewel showed no sign of rust or surface cracks after 3 800 000 impacts. The jewel was then cleaned, freed of oil, and the test was continued. After another 37 000 impacts, surface cracks developed and rust was produced.

A test carried out with a sprung jewel gave the same results as one that was not sprung. This was to be expected, as even if it is assumed that a sprung jewel will be protected by springing, impacts due to transport will possibly be felt by the side of the jewel, the impact force in this case being in such a direction that the spring is of very little use.

The impact apparatus was used to test a softened steel pivot, and rust was also produced in this case. In almost every instance a grey debris seemed to be formed on the jewel before any rust appeared; this feature is mentioned later.

Several tests were carried out on a diamond jewel with steel pivot, and in no case could rust be formed. When the jewel and pivot were examined after the diamond had been subjected to 10 000 impacts, a small quantity of what appeared to be dust was found on the jewel. This substance had a black appearance when viewed by artificial light, and appeared grey in daylight. The test was continued for 40 000 impacts, and further examination showed the condition to be unchanged except that there was a greater quantity of the debris.

In order to investigate the sapphire-oxygen theory and the readiness with which rust is produced on the sapphire-steel combination by impacting, two further tests were conducted in an atmosphere of nitrogen. The following procedure was adopted. A cylinder of nitrogen which contained hydroquinone was connected to the chamber shown in Fig. 22 via two phosphorus-pentoxide dryers, the other inlet to the chamber being connected to a vacuum pump. The whole apparatus, right up to the main valve of the nitrogen cylinder, was exhausted three times to within 3 to 4 mm of absolute vacuum, nitrogen being released into the pipe-line up to the vacuum side of the chamber after each evacuation. It would appear that this procedure should ensure there being less than 1 part in 100 millions of air within the chamber, excluding, of course, any gas occluded in the metal. During the test the nitrogen pressure within the chamber was

5 lb. per sq. in. above atmosphere. After some hours of operation, rust particles began to form on the jewel.

(7) Rotational Tests in Air and Inert Atmospheres.

In order to overcome certain difficulties which presented themselves, particularly with regard to the close examination of the jewel with a microscope, another line of attack was adopted.

For this purpose the piece of apparatus shown in Figs. 23 and 24 was constructed. It consists of a copper cup C, to the top of which is welded a dome of soft iron F, with two holes drilled as illustrated. At the upper end of the supporting stem the jewel is fixed, the pivot being attached to the top of the iron dome. A supporting disc D is fixed to the stem, and the whole unit is mounted within a glass chamber with domed top. The top of the iron dome is fixed as close as possible to the top of the glass dome, sufficient clearance being allowed between the outside of the iron dome and the inside of the glass dome to enable the movement to be lifted on or off by means of a suitable magnet. It is thus possible to view the jewel surface through one of the holes by means of a microscope. These holes enable the observer to see the jewel when replacing the copper cup, and also allow directional movement to be

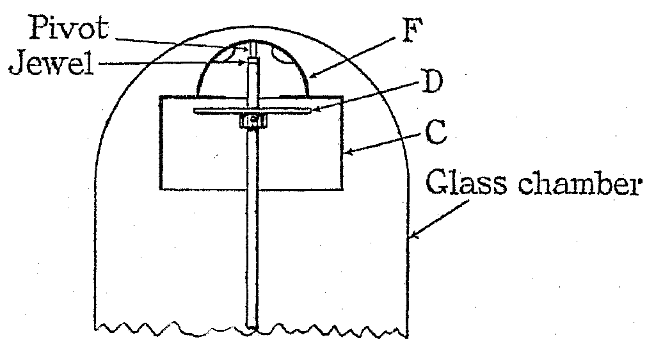


Fig. 23.

imparted to the element when the magnet is being used. The whole unit is mounted between three electromagnets energized from a 3-phase supply and placed 120° apart, as shown in Fig. 24. The rotational speed in atmospheric pressure is 300 to 350 r.p.m.

Several preliminary runs were made with this apparatus in air, to find out its capabilities of forming rust.

The first test was made with a sapphire jewel and steel pivot. The optic axis of the jewel had previously been approximately determined by means of polarized light, and had been found to make an angle of practically 90° with the base plane. The speed was 300 r.p.m., the weight of the movement 25 g, and rust was formed after 23 000 revolutions had been completed. A second jewel was then tried with the optic axis as nearly as possible parallel to the base plane; in this case rust was formed after 2 250 000 revolutions. It is interesting to compare these results with those obtained in Mr. Stott's experiments on the influence of the orientation of the optic axis. A third jewel was tried, having its optic axis nearly as unsuitably oriented as the first jewel; in this case rust was produced after 55 000 revolutions. The jewels used in these three experiments were all synthetic. A natural jewel was then tried with its optic axis inclined at practically 90° to the base plane. Rust was formed on this jewel after 1 500 revolutions. The jewel which had been used in the third experiment was then tested in an atmosphere of nitrogen under the same conditions as those outlined for the impact test; rust was produced after approximately the same number of revolutions as in air. This bearing was left to run for about 12 hours, by the end of which period copious quantities of rust had been produced. Fig. 25 (see Plate 2) is a photomicrograph of this jewel. The natural sapphire mentioned above was then tested in nitrogen, and it was found that rust was produced after approximately 1 500 revolutions. This bearing was left to run for some 24 hours, and very large quantities of rust were thus produced.

In order to ensure that there were no traces of oxygen, water vapour, or any occluded gases in the chamber, the

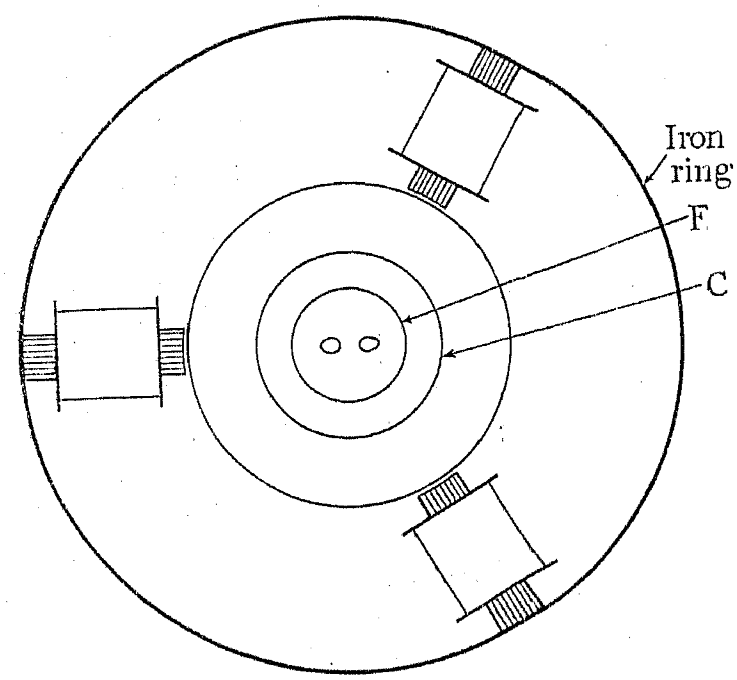


Fig. 24.

rotational units were sealed within the glass bulbs shown in Fig. 26 (see Plate 2) under similar conditions to those in which gas-filled and vacuum lamps are manufactured.

The process under which the elements were filled is described in the following terms by Mr. Everett, of the Edison Swan Electric Co.

"All mounts, after being sealed into glass bulbs, were exhausted to the following schedule, each bulb being separately exhausted.

"The bulbs were first sealed to a glass manifold connected to the exhaust system and opened to the rough vacuum line, tested for leaks, and, if found satisfactory, were then opened to the high-vacuum system, which consisted of a Gaede mercury pump together with a mercury condensation pump.

"A gas-heated oven was then lowered over the bulb, which was thereby heated to between 400° C. and 410° C. for 15 minutes. After this period the degree of vacuum in the bulb was measured by means of a McLeod gauge and found to be 0·000018 mm of mercury. The vacuum valve was then closed and 2 in. of pure argon allowed to enter the bulb, which was baked at the same temperature as before for a further 5 minutes in order to flush out all metal parts and the inner portion of the glass bulb.

"After this period of baking the bulb was again

opened to the high-exhaust system and evacuated until the McLeod gauge read 0·000018 mm of mercury. The oven was then raised and the bulb allowed to cool to room temperature, when (*a*) vacuum bulbs were sealed off, and (*b*) gas-filled bulbs were filled with gas to a pressure of 20 in. and then sealed off.

"The above schedule is very much longer than that used for commercial lamp exhausting. Past experience based on the exhausting of bulbs having a considerable amount of metal indicates, however, that the schedule should be very satisfactory.

"The temperature of the bulbs was carefully checked both with thermo-couples and with thermometers.

"The argon and nitrogen used were rolled in cylinders containing a mixture of hydroquinone and caustic soda for 36 hours to remove oxygen. The gas was then passed through three copper tubes filled with copper oxide and electrically heated to 400° C., after which it was allowed to pass through a further tube heated to 450° C. and filled with copper chips which had been first reduced in hydrogen. Here any traces of oxygen in the gas combined with the heated copper. The gas was then passed through a series of large containers containing phosphorus pentoxide, which removed any trace of water vapour. The gas pressure in the circuit during this process was approximately 10 lb. per sq. in., and this was later reduced to 3–5 lb. per sq. in. according to the type of work in progress.

"The neon gas was obtained in cylinders as 98 per cent neon, 2 per cent helium; and to remove traces of nitrogen the gas was kept in contact with a calcium arc in a sealed container for approximately 50 hours.

"Extreme precautions were taken with the gases used in these experiments to ensure that all traces of water vapour were removed, and the bulbs were not finally filled until it was certain that this was the case."

Four units, constructed and treated in the above manner, were filled with the following gases: nitrogen, argon, neon, and hydrogen. A fifth unit was evacuated to approximately 0·000018 mm of mercury, the residual gas being argon.

The jewels, with the exception of that inserted in the vacuum bulb, were specially selected with their optic axes as nearly at 90° to the base plane as it was possible to judge with the apparatus available, using polarized light. Prior to insertion in the bulbs, they were run with their respective rotors in air so as to determine the number of revolutions required to produce rust. The results obtained, and the particulars of the jewels tested, are given in Table 2.

With regard to the jewel tested in the vacuum chamber, this was not tested prior to insertion nor was the direction of the optic axis observed. (This bearing had been made up before the others in order to try out the effects of the high temperature on the component parts.)

After the air tests had been made the pivots and jewels were thoroughly cleaned with steam before being inserted in their respective bulbs.

It was observed that in every test in air a greyish debris formed before any sign of rust appeared. In explanation of this the author would suggest that, if the polished surface of the sapphire (and possibly of the steel) has physical properties differing from those of the material below the surface,* it may be that the phenomenon of rusting associated with the normal crystal sapphire in air is modified until the polished surface has been worn through. It is also possible that the debris may be more of the form of that associated with the wear on diamond-steel bearings.

Turning to the results of the tests, the starting speeds (in r.p.m.) of the various units were: hydrogen, 165; argon, 430; neon, 380; nitrogen, 345; vacuum, 620. After 25 million revolutions the speed of the vacuum unit rose to 700 r.p.m. The hydrogen unit and the argon unit ran with varying speeds and finally stopped after $1\frac{1}{2}$ million revolutions and $4\frac{1}{2}$ million revolutions respectively. The neon unit and the nitrogen unit are still running after $7\frac{1}{2}$ million revolutions at approximately the same speed.

Microscopical examination of all the above units shows no signs of rust, but in every case debris is present, the maximum quantity being found in the argon and hydrogen units and the minimum in the vacuum unit. Up to about 13 million revolutions no wear was apparent in the vacuum unit, but it exhibited a small wear ring after approximately 15 million revolutions. In all cases the sapphire jewel had a matt appearance at the end of the test, and the debris was of a greyish colour suggestive of a mixture of sapphire and steel particles.

TABLE 2.

Jewel No.	Number of revolutions to produce rust in air	Type of jewel	Gas in bulb
N.2	4 500	Natural sapphire	Hydrogen
S.8	85 000	Synthetic sapphire	Argon
S.5	4 500	Synthetic sapphire	Neon
S.7	67 000	Synthetic sapphire	Nitrogen

These tests seem definitely to disprove the theory, in its simple form, that oxidization of the steel particles is produced directly by oxygen derived from the sapphire. On the other hand, it is still conceivable that the sapphire gives up its oxygen but that water vapour and/or oxygen is necessary to act as a catalyst.

To test whether this is the case another unit was constructed in which the heating and evacuation were done as described above, but oxygen which had previously been washed in phosphorus-pentoxide driers was used. The jewel used in this unit became coated with rust in air after 370 000 revolutions, and when started in the sealed unit it ran at 300 r.p.m. After approximately 500 000 revolutions large quantities of rust were formed.

Further tests are being carried out in an attempt to make quite certain that the oxygen used is perfectly dry. In the first rotating test in nitrogen, and also in the oxygen test, only phosphorus-pentoxide driers were used, and in both cases water vapour may have been present.

The following outstanding queries arise in the author's mind:—

(1) Why, when platinum (a material which is normally

* See R. J. BRAY: "Pivots and Caps in Compasses," p. 14.

unattacked by atmospheric conditions and when used as an anode in electrolysis) is used as a pivot material on dry sapphire, a copious fawn-coloured debris is produced at a low speed, and at a higher speed and greater weight a black debris is formed.

(2) If the oxygen from the sapphire is not necessary to produce rust, why is the debris from the diamond-steel combination free from rust, although it can be rusted artificially?

(3) If oxygen can be derived directly from sapphire, why did the sealed tests with inert gases show no sign of aluminium oxide of non-crystalline form or iron oxide?

It will be seen that the tests have neither confirmed nor disproved the theory that oxygen is derived from sapphire jewels. Further experimental work will be necessary to substantiate this theory.

In conclusion, the author would like to thank Mr. J. M. Donaldson, M.C., Past-President, for permission to publish the results of this work. The author's thanks are also due to his chief assistant, Mr. A. J. Martin, for his invaluable assistance throughout the investigations; to Mr. F. R. Butherus, of the British Sangamo Co., for his help in the construction of the apparatus; to Mr. A. G. Everett, of the Edison Swan Electric Co., for the great trouble he has taken in making up the sealed units and the suggestions he has made in connection with the work carried out in inert gases; to Mr. Beck, of the Cambridge Instrument Co., for assistance in connection with the method of cleaning jewels by means of steam; and to Mr. F. E. J. Ockenden, for kindly taking the photomicrographs.

APPENDIX.

(*Received* 13*th March*, 1934.)

Since the paper was written further research has been carried out which has shed considerable light on the problem of wear; and the author is of the opinion that a stage has now been reached when some general conclusions can be stated. Ten more units have been made, and for simplification the chronological order in which they were constructed will not here be adhered to. On page 769 of the paper the last test mentioned was on a steel-sapphire combination running in oxygen which had previously been dried by means of phosphorus pentoxide and it was stated that the presence of water vapour still seemed possible. Unit No. 7 was therefore constructed with a sapphire-steel combination in oxygen. The oxygen in this instance was kept in a phosphorus-pentoxide chamber for 14 days, after which it was passed through a liquid-air trap before being admitted into the unit. The unit was subjected to the process previously outlined as regards heating and evacuation.

The initial speed of this unit was 300 r.p.m., and after approximately 40 000 revolutions, i.e. after about 4 hours' running, the unit stopped. Upon examination, a large quantity of sooty black debris was found in the cup, and, on tilting the latter, the debris readily altered its position and did not cling to the surface of the jewel as occurred with red oxide.

The debris was shaken off the jewel and another run was started, using in this instance the stator of a 3-phase induction motor, as the friction was found to be too great for the starting torque of the normal unit. After approximately 50 000 revolutions the jewel cup was again found to be full of black debris. It may be of interest to mention that the jewel used in this test produced rust after 300 000 revolutions in air.

A further unit (No. 8) in which the oxygen went through a similar process to that described, was constructed in order to confirm the above results. The speed of this unit at the start was 400 r.p.m., and after approximately 300 000 revolutions the unit was examined and the jewel cup was found to be nearly half-full of black debris.

On page 769 of the paper reference is made to a hydrogen-filled unit which stopped after $1\frac{1}{2}$ million revolutions. This unit having inadvertently been broken, the opportunity was taken of examining it more closely under a microscope. The jewel was found to be badly worn and the debris appeared to be a mixture of sapphire and steel particles. The pivot was also found to be badly worn and flattened, but there was no sign of rust or black oxide. This jewel was a natural sapphire and produced rust in air after 4 500 revolutions.

Another hydrogen unit was then made up, but in this instance no liquid-air trap was used as a final precaution against water vapour. The initial speed of this unit was 350 r.p.m., and after approximately 200 000 revolutions the unit slowed up owing to the formation of rust. Since the hydrogen was passed through a calcium arc it seems impossible for any oxygen to have been present; consequently it would appear that the rust was formed by a slight trace of water vapour which had passed into the unit.

A third hydrogen unit was therefore made up in which the hydrogen was passed through a liquid-air trap. The speed of this unit at the start was 400 r.p.m. The unit was examined after running 19 million revolutions and there was no sign of rust or black oxide. The unit was broken open at this stage, and a final examination showed the presence of steel-coloured debris on both the pivot and the jewel.

As a matter of interest another unit was constructed in which a mixture of oxygen and hydrogen was admitted into the bulb. This unit was constructed at the same time as hydrogen unit No. 3 and oxygen unit No. 7; and the oxygen and hydrogen used in it went through the same process, and came from the same source, as those used in these units. Consequently they acted as check units on the oxy-hydrogen unit, i.e. if the black oxide appeared in the oxygen unit and the rust did not appear in the hydrogen unit this would indicate that the oxygen and hydrogen were dry: it has been shown above that this is apparently true. The initial speed was 300 r.p.m., and after approximately $\frac{1}{2}$ million revolutions a reddish debris, which appeared to consist of rust, was formed in the cup. When this unit was broken open, microscopic examination confirmed that the debris was rust.

Although the author felt that the theory that the oxygen is derived from the sapphire had thus been disproved, he thought that experiments on materials which did not contain oxygen might throw further light on the subject of wear and, at the same time, act as an indirect

check on that theory. Three experiments were therefore carried out with steel pivots and cups. The cups were of hardened and polished steel, and their radius was approximately the same as that of the sapphire cups.

The first experiment was carried out in air, the rotor having the same weight as in the sealed units. The speed of the unit was at first 200 r.p.m., and after a 2 hours' run a fair quantity of rust was formed.

The second was a sealed unit containing dry oxygen which had not been in contact with phosphorus pentoxide for a long period, but a liquid-air trap was used. The speed of the start was approximately 600 r.p.m., and after a $2\frac{1}{2}$ hours' run very dark red debris was found in the cup. The unit was again run, and after a further 15 hours a much larger quantity of debris was found in the cup. It is interesting to note that the exposed part of the cup is still highly polished, and it is also evident that a slight trace of water vapour was present.

The third steel unit was sealed with a high degree of vacuum as in the previous vacuum unit (No. 5). The speed of this unit at the start was approximately 650 r.p.m., and after 9 million revolutions the unit was still running at the same speed. Examination showed that although the running surface of the cup was disturbed and parts of it seemed to have a slightly matt appearance there was no sign of any debris. This unit seems to throw considerable light on the phenomena of wear, and to provide some idea of the amount of friction caused by the oxides. The following facts should be noted:—The weight of each rotor is approximately 25 grammes and the starting torque of the units 160 dyne-cm. Where the oxides have been formed the units either stop or run at a low speed and in an erratic manner, this generally occurring after a few hours' run. The fact that a steel unit in a perfectly dry and unoiled condition continues to run at the same speed, with apparently little change in friction, seems to the author to be extremely interesting and to show that the rapid and great increase in friction is due to the oxides formed.

Another experiment was carried out with an agate jewel and a steel pivot in air. As is well known, agate is an oxide of silica with a hardness of 6·5. The unit was run at 300 r.p.m., and after a few hours a light reddish debris was formed and the friction increased considerably. The 3-phase stator was again used and, after some hours, large quantities of white and light red debris were produced. This debris was in layers, some being white and some of light red colour. It appeared from this that the agate layers through which the pivot was wearing varied in hardness and that in the softer layers the agate rather than the steel was worn.

As the author had been unable to produce any observable rust on diamonds, a unit was made up in an attempt to do this.

A diamond jewel and a steel pivot were mounted in a sealed unit filled with dry oxgyen. The speed at the start was approximately 360 r.p.m., and after 9 million revolutions the unit was examined and a small quantity of dark red debris was found in the cup. The unit was again examined after 20 million revolutions and the same conditions as to the debris seemed to exist. One important difference noted with the diamond unit is that the speed has remained nearly constant since the start of the test. The author is of the opinion that this difference may be due to the diamond acting as a burnishing agent owing to its extreme hardness, or possibly its structure, compared with the sapphire, and that a study of the effect of polishing as against abrasion might throw considerable light on the phenomena of wear.

The present position with regard to the original units described in the paper is as follows:—

Unit No. 1 (hydrogen unit) has already been mentioned.

Unit No. 2 (argon unit) was again started and ran erratically until approximately 12 million revolutions had been completed. Examination showed no sign of either red or black debris.

Unit No. 3 (neon unit) has done 30 million revolutions and there is no sign of either red or black oxide. The amount of debris is small and the speed has remained nearly constant.

Unit No. 4 (nitrogen unit) is running at approximately the original speed and has done 30 million revolutions. In this case only a small quantity of debris has been produced which is of a grey colour.

Unit No. 5 (vacuum unit), after approximately 60 million revolutions, has increased slightly in speed and is now running at 750 r.p.m. The unit has done 80 million revolutions, and was examined after 76 million revolutions. No debris could be observed, although possibly if the unit were broken closer microscopic examination would reveal it.

A summary of the conclusions from the whole of the experiments on oxide production is as follows:—

(*a*) In a dry oxygen atmosphere a black oxide of iron, and not the red, is produced; consequently it follows that in the inert gas (free of oxygen and/or water vapour) and vacuum tests on sapphires black or red oxide should be produced if any oxygen is derived from the sapphires.

(*b*) With one exception, neither black nor red oxide has been discovered in the sealed units using inert gases. This exception was the second hydrogen unit, which undoubtedly contained a trace of water vapour; but in any case this does not support the sapphire-oxygen theory, as the other sealed units did not contain the oxides. Perhaps the strongest argument against the theory is the vacuum unit, for the reason that where inert gases are used there is always a doubt in the experimenter's mind as to the possibility of traces of oxygen and/or water vapour being present, whereas in the vacuum unit this possibility is reduced to the absolute minimum.

(*c*) The author would like to emphasize the very rapid rate of production of red or black oxide in the presence of oxygen and/or water vapour. As an example, the sapphire jewel cut with its optic axis parallel to the base plane mentioned in the paper gave rust after $2\frac{1}{4}$ million revolutions in air. This should be compared with the vacuum unit, which has already done 80 million revolutions on a jewel having an unknown optic axis and is still running at the same or a greater speed. Again taking the case of the neon unit with jewel No. S.5, this jewel has produced rust in air after only 4 500 revolutions, whereas up to date this jewel in neon has done 30 million revolutions and there is no sign of either black or red oxide. It is running at practically the same speed as

at the start, thus showing that the friction has not materially increased.

(*d*) The indirect attack on the above theory is contained in the experiments on steel-steel and diamond-steel combinations where exactly the same results under the same conditions are obtained as with sapphire-steel, which seems to prove that the phenomenon of rusting in the presence of oxygen and/or water vapour is independent of the sapphire. The same rapid rate of production of oxide and consequent increase in friction is to be noted. Consequently it appears to the author that the sapphire-oxygen theory is untenable.

Finally it seems to the author that the explanation of the phenomenon of the production of the oxide of the pivot material has to be sought in the extreme activity of the particles produced during wear, particularly at the high pressures, and it is possible that the formation of heat may also play a part in the phenomenon.

From our examination of all pivot materials tested it seems possible to state a tentative theory as follows:—

"In an atmosphere containing oxygen and/or water vapour and where the bearing material is oxidizable, the product of wear is an oxide of the material." The particular oxide formed may depend on the pressure and/or speed. If this is true it will account satisfactorily for the results of all the experiments so far carried out.

Looking at this matter from a chemical point of view, it will be seen that, when steel is used for a bearing, with perfectly dry oxygen black oxide, and with only water vapour present red oxide, are produced. With oxygen and water vapour present, red oxide is again produced, and where dry oxygen and dry hydrogen are present in combination the major portion of the debris is red oxide. Other metals may also produce different oxides under similar conditions.

The author would like to draw attention to the extreme difficulty of obtaining perfectly dry gases, and it would appear that in order to obtain dry gas it is necessary to keep the gas in contact with the "drier" for at least several weeks and as a final precaution to pass the gas slowly through liquid air.

Discussion before the Meter and Instrument Section, 13th April, 1934.

Mr. W. Lawson: The subject of this paper is not unfamiliar to members of the Section, for this is the third occasion on which a paper dealing solely with meter bearings has been presented and discussed. It is the type of paper which, to do it justice, demands more than the few days' previous study that have been allowed, and I feel that we ought to have a further opportunity for discussing it.

With regard to the first part of the paper, the author's methods are so satisfying that one has difficulty in expressing any opinions, and indeed they should not be expressed unless they are backed up by like experimental facts and data. I should have preferred it if the author could have extended his investigations so as to include other makes of meters. So far as the single-phase meter is concerned, it seems to me that he has largely solved the problem. The tests which he has made down to 5 per cent, $2\frac{1}{2}$ per cent, and 1 per cent of full load, and after the meters have been in service, show that the bearings he has been employing in his meters are of high quality.

I find Fig. 1 very interesting indeed, because the author says that the radii of the pivots and jewels were all equal, the rotor weight was constant, and the polish and material of the pivot were the same throughout. Why, when one has practically the same conditions, should not one get the same results from all those meters? The explanation seems to me to be the different conditions encountered in service. The bearings of some meters, perhaps where the consumer does not use many units or has a relatively low load, are not subject to the same destructive forces as those of heavily loaded meters. Again, there is the question of the vibration of the rotor. We find that some meters are more susceptible than others to humming due to vibration where there are harmonics on the system, and this may apply to meters of the same make. A means of measuring the relative sensitivity of meters to those conditions, devised to select meters in the test room which would not hum on circuit, has revealed that meters differ considerably in regard to this characteristic.

Respecting vibration, it is of interest to note that the diamond jewel is not giving us such good results on 50 cycles per sec. as on 25. At present, owing to the change of frequency, we find with off-circuit meters that the diamond jewels are not in such good condition, owing either to the higher torque or to increased vibration. One comes to the conclusion that, assuming jewels and pivots and oils to be of the best quality, in order to get the best wear out of these we must reduce the forces in the meter. The side thrust has a bad effect, particularly on an inverted jewel. The author's results indicate that what we are up against is first of all the quality of the material supplied by the manufacturer, and secondly the forces at work in the meter tending to destroy the jewel. It seems to me that those are the two lines along which we must go in order to get the most satisfactory results so far as single-phase meters are concerned. The polyphase meter presents a far more difficult problem. Agate pivots, for instance, will stand up well for millions of revolutions in a single-phase meter, but will rapidly break down in a polyphase meter. A well-designed polyphase meter would not be so destructive to its bearings as existing designs certainly are.

With regard to the use of oil, the results obtained by the author are those which one would expect. Wherever there is friction one naturally turns to oil, and there is no question that it does have the effect of reducing friction and prolonging the life of bearings. A case is mentioned in the paper where a decrease of friction occurred with the continuance of the wear on a dry bearing. I have myself noted a similar case, that of a polyphase meter the pivot of which wore down so much that the disc fouled the series coil. When the meter was tested after removal it was found to be not nearly so inaccurate as one would have expected on low loads. This result led me at the time to consider the possibility

of a dry lubricant. This dry-lubricant effect is noticed when one uses an agate with a sapphire; the agate is powdered so finely that it does not seem to have much effect in producing friction.

With regard to the final part of the paper, I am interested in the author's attack on the sapphire-oxygen theory. His conclusions are convincing, and his suggested law as to the effect of oxygen and water vapour is also, I think, sound.

Mr. E. G. Sandmeier: The results of the various tests carried out by the author offer many points of interest. As regards the sapphire-oxygen theory, I am convinced that the production of debris cannot be ascribed to a chemical action between oxygen from the sapphire and iron from the pivot. The explanation must be sought in an essentially mechanical action between the two parts in contact. The state and composition of the debris derived from the pivot are influenced by the surrounding medium, while the debris from the jewel is not subject to modification.

The experiments of the author seem to offer sufficient proof of this explanation. It is further supported by the results of a series of micro-chemical tests I have carried out with a view to ascertaining as exactly as possible the nature of the red or brown mass found on dry jewels working under normal conditions. In all the cases investigated I found the brown mass to be an agglomerate of a compound of iron and sapphire particles. After the red part had been dissolved in hydrochloric acid, the sapphire particles became clearly visible, especially in polarized light, where they showed double refraction. In every cup tested I counted at least 50 single grains; in a few, more than 250. Their sizes ranged from 0·01 mm as the largest diameter down to microscopic dimensions.

It would therefore appear that the real causes of wear are not to be sought in otherwise unknown influences, but that they find their explanation in the nature of the two bodies in contact, the conditions of their running surfaces, and the pressure of the rotating element on the bearing.

I entirely agree with the author that the rate of production of wear does not depend on these factors alone, but also on various secondary factors, including, in addition to the speed of the moving element and the time, the atmosphere in which the two parts are working. The surrounding medium is responsible for the form in which the product of wear is produced from a metallic pivot, whilst it does not influence the composition of the debris from the crystallized part of the bearing, if this be a mineral like sapphire or diamond.

Mr. E. W. Hill: So far as the actual record in the paper of the experimental facts and observations is concerned, I think no one could contest them unless he had himself conducted comparable experiments and had obtained results which differed from or contradicted those obtained by the author. The conclusions to be drawn from the facts obtained by experiment, however, are more debatable. Even so, I, for one, find it extremely difficult to discover any grounds for dissent from his conclusions, particularly those in Section (7). These conclusions are summarized in the Appendix, and I think they are eminently just and properly deducible from the facts.

In discussing the problem of the source of the oxygen, however, the author has the temerity to put forward the suggestion that the oxygen may be derived from the sapphire. This is a very grave assault upon one of the most cherished convictions of the chemists. The bond of chemical affinity holding together the oxygen and aluminium atoms in the aluminium oxide which constitutes the sapphire, is one of the most tenacious bonds known to chemical science, and it is a bond which the chemist utterly refuses to believe can be disrupted by the mere tickling of a steel pivot on the surface of a sapphire. In spite of that, however, at one time it seemed as though we should have to join issue with the chemists upon that very point. There were several reasons for this. At that time it did not seem so outrageous an idea as it may now seem to us. The author, in Section (6), describes some impact tests with a steel pivot on diamonds in which no rust occurred. That was a very extraordinary and anomalous result to obtain. Consider the position. We have a steel pivot rotating on a diamond. The diamond contains no oxygen; the whole thing is in an oxygen-permeated environment—the atmosphere, in fact—and no rust appears. On the other hand, if we merely substitute a sapphire for the diamond and make no other change, rust appears almost immediately. This result certainly begot a very strong suspicion that the oxygen came from the sapphire, and to my mind even now the result of that experiment forms an obstacle to the full and complete acceptance of the conclusions which the author has been forced to draw from the results of his other experiments. I do not feel at all easy in my mind about that outstanding experiment with the diamond, and I should be glad to have the author's latest views on the point. I find that in the Appendix he makes a suggestion which provides a kind of answer to my query. This suggestion can be paraphrased thus: that the production of rust demands not only the presence of oxygen but also of some sort of debris produced by abrasion. The diamond does not abrade the steel and does not produce the debris, and therefore one of the two essential ingredients for the formation of rust, namely the debris produced by abrasion, is missing. The diamond, it should be noted, does not produce abrasion; in my view, instead of abrading the steel it burnishes and polishes it.

It may be that we are laying too much stress on rust *qua* rust. The results of the author's experiments on the various combinations of materials used respectively for pivot and jewel show that the debris, whether rust or not, is always detrimental to the functioning of the bearing as a bottom bearing in the meter. It seems, therefore, that what we have to do to secure a good bottom bearing is to choose the two materials for the pivot and the jewel respectively which produce least abrasion. Incidentally, in the choice we have to take some account of the plane of cutting of the jewel, i.e. the orientation of the cup of the jewel in relation to the optic axis; because, we have reason to believe, that plays a very large part in the behaviour of the jewel. Finally, as an extra and very important safeguard, we have to choose an oil of the proper characteristics to minimize the effect of what abrasion still remains.

In connection with oil I have a query to put to the author. On page 755 he asks the question, "Does oil prevent the formation of rust?" and goes on to say that that question is probably best answered by the curve shown in Fig. 1. To my mind, that curve shows that, as a statistical average, the percentage of jewels working with grease or oil which show signs of rust steadily increases with the number of revolutions that are performed on the jewel; but I should like the author to explain how it indicates whether oil prevents rust, and whether the answer to his question, as deduced from the curve, is yes or no.

Towards the end of Section (1) the author says: "The experimental data obtained with oiled jewels show that their performance is at least 30 times better than that of dry." I must assume here that the inference that oiled jewels are better than dry cannot be drawn from the data given in the paper. That, however, is a small point; the real point is, how does one arrive at that factor of 30? How does one allot factors of merit to such things as the behaviour of jewels? Is the basis for judgment the fact that, for example, one jewel runs 30 times as long as another before rust appears, or is it that one jewel in a given length of time shows $\frac{1}{30}$ of the increase of friction as compared with another?

The fact that the paper was written while the experiments were being carried out makes it rather more difficult for the author to get a proper perspective of the results of his work and to analyse it properly. Has he any further reports, obtained since the paper was prepared, to make upon the behaviour of jewels and pivots within gas-filled bulbs?

The author has, in this paper, acted as a kind of consultant in diagnosing a difficult case, and he has told us more or less what is the matter; but we should like to know what to do about it, and therefore I want to ask him what material for the pivot he would suggest instead of steel.

Lastly, there is one point which is very important from the point of view of the user, and it is this: that after a meter has been in service and the pivot and the jewel have both become fairly well worn and, through the instrusion of debris and rust into the running surfaces, it behaves badly, will that meter behave well again if the rust and debris are cleaned out without the pivot and jewel being renewed?

Mr. F. E. J. Ockenden: As long ago as 1929 I remarked at a meeting of this Section that a lot might be done if all jewels, before going into service, had their optic axes identified by means of polarized light and the results were filed for reference for comparison with the behaviour of those jewels. Later on, Mr. Stott pointed out that although the optic axis was of interest, X-ray analysis was required to show the complete crystal orientation of the jewel. The author told me recently that he has now reached such a stage in this method of testing the jewels that he can anticipate, by the performance of the jewel, what the optic axis will be, and his judgment usually turns out to be correct. If this means that we can eliminate X-ray examination and use only the polarized light, it means a very great and useful simplification.

One of the outstanding features of the paper is the discussion and description of the debris which forms in the base of the jewel. The author says that sometimes it has a grey metallic appearance. In the case of iron, it usually turns to red, dark red, or black, and in the case of the other materials fawn-coloured deposits, for example, are obtained. I do not think that a great deal of attention need be paid to the colour of the deposit. For example, Fig. 25 shows a comparatively simple case of a red rust deposit from a steel pivot, on a sapphire jewel. It is a vertical view taken by reflected light, and shows the rust by reflection. When it is examined by transmitted light a brilliant orange patch appears in the centre which does not show by reflected light. Plainly there we have two coloured deposits; no doubt they represent the same thing, and it would be a mistake to assume that, because there is a brilliant orange patch there, it implies that some mysterious effect has been going on in the process of oxidization of the jewel. Then again some deposits are merely a mixture of red and black oxide, which, in some cases, become completely black oxide. As regards the fawn deposits, it seems extremely probable that these are oxides of the metal concerned, but we must bear in mind that the oxides of metals are abrasives, and it seems possible, in cases where great wear has not occurred in spite of the presence of deposit, that it is not in fact the oxide but merely the metal itself in a fine state of subdivision. There are many instances where the colour of a metal is completely changed by the method or degree of subdivision. Platinum in the finely deposited state is dead black—platinum black. Another example is the old-fashioned red stained glass, in which the brilliant red colour is due to the presence of colloidal gold! Colour, therefore, cannot be taken too much as a guide.

Quite by chance, Mr. Pitt gave me a diamond jewel to investigate some time ago, because he said it had a "pip" in it which he could feel with a needle but could not see. Fig. A (see Plate 2, facing page 757) is a picture of it. One of the interesting features is that the diameter of the pip is only 0·004 in. and from Mr. Pitt's figure of the weight of the system I estimate that the pressure on that pip was of the order of 4 000 lb. (nearly 2 tons) per sq. in. The depression, moreover, is very highly polished; so much so that it is possible to focus the base of the jewel independently through that mark and get a separate focus and separate image, which is as bright as the main image, showing that the surface is optically perfect. It is 0·001 in. in depth, and therefore some debris must have been produced when it was being made. Assuming that the debris is produced alike with the diamond and with the sapphire jewel, it would appear that the author's theory is correct. Some catalyst is required to promote the formation of the oxide, and whereas the sapphire debris would act as a catalyst the diamond debris would not.

Coming to the question of materials for pivots, I think the author has shown great prescience in making tests on other materials—aluminium, tungsten, platinum, stellite, and so on. In this connection, I should like to advance the only criticism which I have of the paper, and that is that he, in common, apparently, with a great many other people, is under the impression that stellite is extraordinarily hard. Now, that is not the

case. Stellite does not compare in hardness with glass-hard steel or even with tempered steel provided the tempering is not carried too far, but its useful features are (*a*) it is impossible to destroy that hardness by heat treatment, and (*b*) the hardness is not obtained by the locking action of iron-carbide particles, iron being present only in the proportion of 5 per cent and there being no carbon present at all. We have therefore an example of hardening by another process well known to metallurgists, which consists of crystal distortion; that is to say, the sliding planes of the crystals are so distorted by the presence of the alloy that the crystals are no longer free to slide. Here then we have a useful hard material, and one of which the hardness is not produced by the influence of particles which are harder than the sapphire itself. The paper shows that the behaviour of the stellite, once oiled, was extraordinarily good, and I believe that the future of pivots for meters lies in the provision of some material which, although sufficiently hard, does not depend for its hardness on the locking action of carbide of iron.

Mr. A. Felton: The object of the mechanism for producing surface cracks does not appear to be obvious. It is stated that many jewels taken from service are observed to have surface cracks and it is suspected that these are produced by vibration in transit to the consumer's premises. The simplest method of testing this assumption would surely be to examine a meter after it had been transported in the usual manner, and before it was put in circuit. The author's results show that cracks may be produced after 30 000 impacts. Is it suggested that a jewel suffers this number of impacts in transit between the manufacturer's works and the consumer's premises?

The electrical method of demonstrating the existence of an oil film between a steel pivot and a tungsten plate is interesting, and the fact that the two materials appear to be insulated from each other indicates fairly conclusively the presence of a film between them. On the other hand, had the test shown that the contact resistance was low it would not have been evidence of the absence of an oil film, since in many cases a thin film of oil between metal surfaces in contact under pressure conduces to a low contact resistance.

Mr. E. Fawssett: This paper is a record of a very fine piece of experimental work, done by a man who loves his job. Section (1) illustrates particularly how very well the author has been able to control his experiments. He has, of course, been in the fortunate position of being able to confine his work to one type of meter, and that has been an enormous help. Hardly any of us can do that, and as the essence of a proper laboratory test is to control as many of the variables as possible, the author has been very well situated in that respect.

With regard to Fig. 10, I have made tests on vaseline in air, and have found that after a time it attains the consistency of cheese. I suggest that vaseline or anything of that nature is too viscous, while at the other end of the scale Sangamo oil is probably too thin. I think the author would have obtained a rather different set of results in Fig. 10 if he had used an oil of fair viscosity, at any rate of higher viscosity than the Sangamo oil. I should like to ask for the previous load history of items (*a*), (*b*), and (*c*), and also to inquire where the pivot had been running on the jewel in each case.

The apparatus for steam-cleaning jewels is very interesting and most ingenious. I should like, however, to offer a possible alternative which might be cheaper to use. I refer to the use of trichlorethylene, such as is used in de-greasing plant.

The tests with a balance for contact are most interesting. Actually that arrangement, it seems to me, employs a slightly higher intrinsic pressure than normal. It is a pivot working on a flat plate, as against a curved surface in practice, so that it seems to prove the case exceptionally well. On the other hand, I should like to see a series of rotational tests made with a "metallic jewel," i.e. a piece of shaped steel.

With regard to Section (5), it seems to me that, between the times when it is examined, the pivot is not running on the same wear circle on the full-load as in the case of the low-load tests, so that rather too optimistic a result may be given in all those tests. For, if the pivot were run at 25 r.p.m. and 5 g-cm torque, between the times of measurement on low load it would be running on an outer ring, whereas the low-load tests are made with the pivot on the middle of the jewel. I should like to know rather more about the very promising sapphire-steel combination lubricated with oildag: it would be of interest to have some further history after the 10 million revolutions. The other most interesting one, because it does not involve the use of oil, is the sapphire-sapphire combination, and there again I should like to see tests in which the sapphire pivot is moved about and is also tested over the whole wear circle.

Turning to the most debatable question of rust, I am very interested indeed in the platinum test mentioned at the top of page 767, and I wonder whether the debris may have been a mixture of the pivot and the jewel in the cases where it is possible to say that the pivot and jewel are normally non-oxidizable. It seems to me that all these tests show how extremely severe the working condition in a meter is, the intrinsic pressures being enormous. The maximum pressure at the centre point, something of the order of 50 to 100 tons per sq. in., is sufficient to deform the pivot, and it may be that that point of maximum pressure is where the damage is being done. Chemical changes may be taking place there which are quite outside our experience to date. My own view is that the oxygen may still be coming from the sapphire under these extreme conditions, but that it does so only when there is a catalyst present to make it possible.

The two tests on the diamond are very interesting. In the one described in Section (6) a substance was produced which appeared black by artificial light and grey in daylight. I should like to ask the author what he suggests that substance is.

On page 768 he refers to a unit consisting of a natural sapphire and a steel pivot which was tested in nitrogen and was found to produce rust at once. It seems that the cause is the presence of a trace of oxygen or water vapour, and, although the author does not say so, he rather infers it both by what he proceeds to do and by his statement at the bottom of page 769, to the effect

that he is doubtful whether the oxygen used was perfectly dry. With regard to question (1) which he asks on the same page, possibly the answer to this may be that the effect is a function of the size of the particle. With regard to question (2), does the diamond, under these intense pressures, possibly act as a reducing agent? That may be a revolutionary idea, but it seems to me that anything may happen under these intense pressures, about which little is known. At any rate there is a suggestion to think about. At the bottom of page 770 the author says: "The initial speed was 300 r.p.m., and after approximately $\frac{1}{2}$ million revolutions a reddish debris, which appeared to consist of rust, was formed in the cup." Is it possible that under these intense pressures the hydrogen and oxygen combined to form water vapour? Turning to page 771, the author refers to the experiment where a diamond jewel and a steel pivot were mounted in a sealed unit filled with dry oxygen. Is the reason for the different result obtained there that the oxygen atmosphere is overpowering the possible reducing action of the diamond? What would happen if only water vapour and no free oxygen were present? Is the water vapour split up, or does the oxygen come from the sapphire?

Mr. G. A. Cheetham: The author has investigated one of the most elusive subjects connected with meter engineering, and in the results which he has obtained I think we have the research worker at his best.

The results shown in Figs. 4, 5, 6, 7, and 8, demonstrate conclusively the advantages of a light rotor, and it would have been very interesting if the author had been able to conduct the same experiments with rotors of different weight. I think that would have given us a very complete justification of a light rotor in a meter. It is well known that a heavy rotor produces rust much earlier than a lighter one. Although the lighter rotor generally produces more rust due to vibration alone, the errors with that rotor when wear has taken place are usually much less than with the heavier rotor; the constant vibration seems to give similar results to tapping a meter, and reduces the error.

It will be noticed that, although the subject of wear on jewels and pivots is a very important matter from an engineering point of view, the actual errors due to jewel wear are, over a long service, small, and I am very glad that this paper has been written, so that the whole matter can be seen in its true perspective. We have heard for years a great deal about jewels and pivots, and we know that these are the weakest parts of a meter, but the author has now given wide publicity to the subject in its proper perspective. He is probably aware that in obtaining the results of wear he can entirely mask them if very careful attention is not paid to the cleanliness of the top bearing.

I cannot agree at all that his experiments on the existence of an oil film are conclusive; and I cannot see why we should logically expect that, at stresses under which the mechanical engineer knows there is no lubrication, we meter engineers should find it in our particular apparatus. I am going to put forward some evidence with regard to this. It is very well known that by measuring the logarithmic decrement of a rotor we can calculate the combined friction of the top and bottom bearings, and we can repeat those results on dry bearings to a very high degree of accuracy; in fact, it is remarkable how consistent the results are. Now if we oil the top bearing and repeat the process the results differ; we get reduced friction when the top bearing is oiled. When we oil the bottom bearing, however, there is no difference at all. In my view it is inconceivable that there is an oil film there and that those results can be repeated so accurately. There is another piece of evidence in favour of this. If in a deoxidizing atmosphere we place a rotor on a jewel and do not rotate it but leave it until rust takes place, we find that the rust forms a ring down the pivot but never at its top; consequently the pressure there must be sufficient to exclude air. If it is sufficient, however, to exclude air, I cannot see how oil can enter. I know the author's results seem conclusive, but, like another speaker, I feel that this point has not been thrashed out. It is only of academic interest, of course, because we know the oil is necessary and is a considerable improvement.

The author is probably aware that in 1927 Prof. Schachenmeier gave* results of experiments with a metal cup, on the lines that Mr. Fawssett has mentioned, to prove the contention that there is an oil film below the pivot. Prof. Schachenmeier is very satisfied and so is the author.

I am in entire agreement with the conclusion to be drawn from the curves in Figs. 13 to 21, that increasing the hardness of the material of the pivot does not improve the resistance to wear. It is now possible by a certain process to harden pivots so that they will cut glass, but no improvement is thereby found in the wearing properties of the pivots.

With regard to impact, the impact produced by the voltage element is very important. Some time ago I conducted some experiments on impact and came to the conclusion that it ought to be evident in the form of noise. The noise from a meter should come from two sources: (1) the vibration of the laminations, and (2) the impact of the pivot on the jewel. If anything could be done to reduce the noise, apart from that coming from the laminations, we should be reducing the impact, and thereby obtaining an increase in the life of the bearings.

(Mr. Cheetham then showed three lantern slides illustrating the methods of mounting the jewel and the relative amount of noise.)

The author has not mentioned the difference between natural and synthetic stones. My experience is that natural stones vary very considerably, depending on the locality from which they are obtained, but that a stone obtained from the best locality tends to have a longer life than a synthetic stone.

I should like to ask the author whether his method of cleaning jewels by means of superheated steam has given any trouble due to the rusting of springs in the case of spring-supported jewels. I should also like to inform Mr. Fawssett that trichlorethylene is of no use for cleaning jewels.

With regard to the author's experiments in Section (7) on orientation, I do not think an examination of the optical axis by means of polarized light is of any use at

* *Elektrotechnische Zeitschrift*, 1927, vol. 48, p. 203.

all in considering the effect of the orientation of the jewel. The result obtained is only an approximation in two dimensions, and not the three-dimensional result that is necessary. We have found that there is definitely a strong tendency indicating that orientation is important, but it is very difficult to reach a conclusion because of the difficulty in obtaining jewels of the same or nearly the same orientation, and then one finds that they have a ratio of life of 2 or 3 to 1. I do not think that proves anything at all. We have still to get down to the physical properties of the jewel and ensure that they are constant, before we attack orientation. My own opinion is that we shall then find something in orientation.

Finally, with regard to the breaking down of the oil film, the author seems to be very surprised, judging by what he says at the top of page 760, that the sticky oil has not produced more trouble; but if he assumes that it has broken the film away from the point it is to be expected that he will have no trouble from it.

Mr. Albert Page: I was surprised in reading the paper to observe that no concrete conclusions had been arrived at. I am going to be so bold, however, as to suggest that the author already knows the solution. From past experience I have found that all engineering problems can be treated in the same manner, and I would suggest that there is no fundamental difference between the jewel problem in an ordinary electricity meter and the problem of turbo-alternator bearings. Friction problems can be divided into three sections, namely, the thermodynamic section of work input to heat output, the chemical or endothermic section of the production of debris, and the mechanical aspect. The last-mentioned, namely the effect of impact, I do not intend to touch upon. It stands to reason that if by impact we crack the brittle bearing surface such as that of a jewel and the crack is on the operating circle, trouble is bound to ensue. Neither do I intend to refer to hardness, as I think the author has demonstrated that soft materials can be made to withstand "wear and tear" equally with hard materials. In fact we find the softer the material the better are its wearing properties, as is seen by the employment of white metal in bearings. This mechanical part of the problem is fairly simple and I do not intend to confuse the issue by elaborating it further. I should like, however, to try to explain the other two aspects, namely the thermodynamic and chemical aspects, by reference from the one to the other. There are a large number of variable factors involved, but I intend only to deal with the general broad aspects. In dealing with thermodynamics, physics, and chemical reactions, every step is absolutely definite and should be capable of a clear explanation. If I take a steel pivot and prevent oxygen, or moisture, or any compound having an oxygen content, from coming into contact with it, I can be sure no ferric oxide can be produced. In Section (7) of the paper the author has gone to elaborate pains to prove the validity of this statement which is practically self-obvious.

One point appears very definite from the paper, namely, that rust formation is the root of the evil. This is confirmed by the curves, and at the foot of page 760, col. 2, it is stated that "When oiled or greasy jewels are employed, the rust is the major cause of the error." The point is further brought out in Fig. 10. The problem therefore resolves itself into why the pivot should rust in direct proportion to the rotation, as shown by Fig. 1, as distinct from a polished spindle which normally remains bright. I will endeavour to postulate an hypothesis which explains the reason.

Chemical activity is dependent entirely on, and can be expressed as, the state of ionization. We therefore conclude that the pivot has rusted as a result of increased ionization in the immediate neighbourhood of the bearing. Ionization is produced by electricity and it therefore becomes apparent that bearing friction is bound up with the generation of current in the immediate neighbourhood of the point of contact. Heat and electricity are closely allied, and it appears not improbable that in our thermodynamic equation of work input and heat output we must include a term covering the electricity generated. Rubbing some articles such as amber produces electricity more readily than others, and the similarity of the argument can be readily recognized. To give a general explanation, let us consider theoretical point contact which must occur somewhere in any bearing. There will be two molecules in juxtaposition having their corresponding negatively charged nuclei and the corresponding revolving positively charged satellites. In other words we have a self-contained electrical system from which there must radiate a corresponding field. The field is, in fact, of considerable intensity and is of such a nature as to prevent actual mechanical contact. If we introduce rotation the electrical field is bound to be intercepted in some manner, with the consequent production of potential, static charge, or eddy currents. Remembering that the area of contact by the deflection is proportional to some power of the loading pressure, it is to be expected that a greater influence will be produced owing to the fields of a greater number of molecules being cut. This point is illustrated clearly by Figs. 4 and 5 in the paper. When a bearing is lubricated, the action is partially arrested by the interposed oil film, which is only a number of molecules thick and, in addition to being an insulator, tends to keep the particles further apart than would otherwise be the case, thus decreasing the intensity of interaction of the fields. The question then arises: is the effect superficial or do the electric currents penetrate to a depth? At first I was of the opinion that the effect is purely superficial and that the conducting path is the film of moisture which is invariably present unless extreme precautions are taken. According to the author's tests, however, with sealed inert gases, deposits, although not rust, are still produced. This partly inclines one to the belief that the effect is not entirely superficial. Conclusive evidence that the electrical flow is more than skin deep is confirmed by the paragraph in col. 1 on page 768 describing tests on jewels having the optic axis parallel to and at right angles to the base plane. The resistance of a jewel along the optic axis is much less than that at right angles to it, as in the latter case each layer forms a separate insulating path. Accordingly we find copious rust produced in the one case and no rust in the other. This supports my claim and, at the same time, explains the phenomenon previously observed.

We can say that if the conduction is good the rust is copious.

I wish now to quote another part of the paper. On page 760, col. 2, the author states that "In all cases the sapphire jewel had a matt appearance at the end of the test, as the debris was of a greyish colour suggestive of sapphire and steel particles." Had the test been made in air the deposit would have been an oxide. Further, analysing the statements on page 764 onwards, in connection with nearly each of 9 tests the phrase appears "The pivot having a running surface of matt appearance." At the Institution last evening Dr. Thompson in a paper* dealing with rectifier equipments said "The burning of the electrodes has been found to take two forms; one results in the appearance of a number of separate craters (corresponding to the description of a matt surface) and the other is the oxidation process. The process deposits an oxide film on the surface which may also become deeply scored." That I contend is precisely the same condition as exists in miniature in the bearings described by Mr. Shotter. We have an electrical process set up by the rotational movement, with consequent ionization, producing precisely the same condition as obtains in an ordinary arc. My hypothesis explains practically every feature mentioned by the author.

I should like finally to refer to Test No. 7 on a tungsten steel pivot, described on page 766. Tungsten steel has peculiar magnetic properties, in so far that in the hardened state it can be made into an excellent magnet. We find that the tests on this steel also give peculiar results and that the properties of the material are evidently very conducive to mitigating the electrical reactions indicated. Referring again to heavy engineering for a parallel, we find that in turbo-alternator practice where a heavy strong field may be produced special precautions are taken to stop this action by insulating the outboard pedestal. It has been found that deleterious effects are likely to be produced similarly to those in these jewel bearings. If we can control the electrical phenomenon, we can prevent the ionization; and I suggest that if further researches are made for the purpose of producing a perfect bearing special attention should be focused in the direction indicated.

The author, I believe, has similar thoughts in mind when he states at the top of page 767 that platinum as an anode in electrolysis does not oxidize; and at the top of page 770 he again refers to this point. If platinum were used for one pole of a rectifier, as distinct from electrolysis oxidation would occur, which is a further proof of what I have described and which the author may have had in mind but did not state in his paper.

Mr. A. G. Everett: I should like to make a few remarks with regard to the help which I have been able to give the author in connection with the bulbs filled with inert gases. The problem which was set seemed to be to fill the bulb with a gas which did not contain water vapour or oxygen. That is a problem which is very akin to what we have to solve in lamp-making. The argon- and nitrogen-filled bulbs contained the same gas as is used in lamp-making, with one difference, namely that the exhaust schedule was considerably longer than is common in commercial lamp-making. When we came to the question of neon, hydrogen, and oxygen, those gases are not used for lamp-filling but for other purposes, in the manufacture of neon lamps and so on, and it would appear that it is exceedingly difficult to obtain an inert gas absolutely free from oxygen and water vapour. It seems, however, that if the author has disproved the theory that the oxygen comes from the sapphire he may have thrown open another field which is of very great importance to the lamp-making industry. On rotating one of these domes inside a bulb filled with an inert gas, if rust is produced it would be an indication that either water vapour or oxygen is present, and as both of these are fatal to the manufacture of good-quality lamps it is quite possible that the author has put something in the way of lamp makers which will be of inestimable benefit.

Mr. F. H. Batt: One part of the paper which is particularly interesting is that dealing with the impact test. As I see it, we are dealing with three forces. One is that due to the shunt flux which acts more or less in a vertical direction. The second is the interaction between the permanent magnet flux and the shunt or series eddies fluxes, which is in a horizontal direction, and, in addition, we have the force produced by the main driving fluxes. The magnitude of all these forces can be determined and they are relatively small. Now in Section (6) the author says "The amount of motion is limited to that normally allowed for the movement in an electricity meter." This he has told us is $\frac{1}{16}$ in. This indicates that in the apparatus he has rigged up for impulses the force is very large compared with any of the above. In view of the fact that with oil we can give quite a number of impulses before there is any bad effect, it would appear that he has rather exploded the importance of this force as compared with the running wear. This assumes that a large impacting force for a moderate number of times is more severe than a small force for a large number of impulses. This seems reasonable, especially where oil is in use. I should like the author's opinion of the importance of this so-called vibrating force.

Mr. Scott Lynn (Canada) (*communicated*): We have accumulated over a period of years a very large amount of data as to practical results in service with our product in all parts of the world. While I am sure that we are reasonably open-minded and prepared to consider any new theories, our opinions are necessarily strongly coloured by the average results in service.

Approaching the subject from this angle, I have a few comments which may be of interest. In the first place, I am very glad to see confirmed so conclusively the desirability of the oiling of lower bearings. I must admit that my own advocacy of this has been from the angle of rust prevention more than anything else. I have always been rather sceptical as to the ability of an oil film to maintain itself, in view of the tremendous pressure per unit of area involved. For this reason I find the tests which the author conducted particularly interesting, and I think they have fairly well established that under service conditions the oil film is maintained to a sufficient extent to be a definite factor in bearing life.

For some years past we here in Toronto have used

* See page 603.

steam for the cleaning of lower bearings. The apparatus developed for this purpose by the author has been of much interest to us. In some respects, particularly as regards the prevention of condensation, we believe it is superior to that which we employ. Our boiler is made of monel metal, which we have found quite satisfactory, and we confirm the necessity of using only filtered distilled water. We arrange for the steam to impinge upon the jewel cup at high velocity, and employ a very fine hypodermic-syringe nozzle.

Our opinion has consistently been contrary to Mr. Stott's theory as to rusting being caused by oxygen released from the sapphires. Our reasoning has been based on experience which closely parallels one step in the author's laboratory proof, namely the production of rust despite the presence of oil and the absence of sapphires. This experience can be divided into two parts: (1) The production of rust in several hundred of our 3-element polyphase meters equipped with diamond bearings, installed on the lines of the Mexican Light and Power Co. (2) The formation of rust on pivots when completely immersed in oil. We have found that (2) will occur if after the polishing operations the pivots are not very thoroughly cleaned with alcohol, or if after cleaning they are allowed to lie unprotected by oil for any length of time. This experience would seem to confirm the author's statement that a very minute amount of water vapour is sufficient to start rusting.

Some 20 years ago I found the surprising condition of a very large amount of rust formation in meters as they were taken from stores and before being put into service, although both the pivot and the jewel were apparently well protected by an oil film. By a fairly extended process of elimination, we traced this to the handling of pivots by operators whose perspiration reaction was highly acid. It was as a direct result of this that we originally adopted the little petticoat which overhangs and protects our pivot from contact with the fingers. At the same time I succeeded with new and perfect pivots in reproducing just what had happened with our product. The rust was produced exceedingly rapidly and had the form almost of a growth on the pivot. With such meters as had gone out into service, the abrasion of the pivot and the cutting of the jewel was very rapid.

Referring to surface cracking of jewels and the various impact tests carried out by the author, I should be much interested in his opinion as to a theory which we hold. I believe that the surface cracking to which he refers is very similar to what we call "checking." The cracks appear on the surface of the cup as minute half-moons. I believe Mr. Holtz's theory is that such "checks" are produced by carrying on the polishing operation at too high a speed, which causes a sharply different condition of stresses on the surface and immediately below it. These checks are observed periodically in new jewels and we have to watch for them very carefully as they are extremely difficult to see under the microscope, and practically impossible to detect by the sense of touch. I have entertained the theory (perhaps a little far-fetched) that these minute checks present a microscopic cutting edge which "shaves" tiny particles from the pivot. These particles possibly constitute the refuse which the author found in a good many cases, and which in the presence of any oxidizing agent is particularly susceptible to the rapid formation of rust.

Mr. J. S. Martin (U.S.A.) (*communicated*): No apology whatever is necessary for undertaking additional investigative work on the subject of meter bearings. The further improvement of meter bearings, particularly the lower bearing, in order to obtain positive assurance of sustained accuracy over considerably longer periods between tests, is to-day more than ever the outstanding design problem of the meter manufacturers.

With regard to Section (1) of the paper, the linear relation between the number of revolutions and the percentage of rusty jewels is strong evidence of the influence of the normal abrasion of the pivot in producing exceedingly fine particles of steel, which are no doubt immediately and completely oxidized under normal operating conditions. The results exhibited in Fig. 1 are especially convincing if the periods of service of these meters have been in most cases about equal.

Turning to Section (2), it might appear that the experiments made with various oils indicate that it is preferable to use a suitable grease instead of the usual light oil. If this is true, is a suitable grease available? A further discussion of the possibility of using vaseline for this purpose would be timely, in view of the author's findings. Such a discussion should not neglect the effect of wide variations of temperature on the properties of the lubricant. In the United States, at least, the growing practice of installing watt-hour meters out of doors compels the choice of lubricants which function well over a temperature range of $-30°$ F. to $+130°$ F.

The influence of slight motion of the pivot relative to the jewel in re-establishing the oil film, mentioned in Section (4), is very interesting. In this connection I would inquire the effect of temperature, especially low temperature, on the stability of the oil film.

Regarding Section (5), the initial drop in meter registration at light loads which seems to occur in every unoiled combination except the sapphire-sapphire, the tungsten-sapphire, and several oiled combinations, must have some significance. The correct explanation of this effect could be very helpful to the meter engineer. Since this initial drop in the curve seems to persist for a relatively few revolutions, it is possible that it might be prevented largely or entirely by some additional treatment of the bearing during the manufacturing process. If, for example, a burnishing operation, such as might be obtained by properly using a sapphire or diamond burnisher in finishing the steel pivot, would anticipate this initial "wearing in" phenomenon, such an operation would justify some additional cost. On the whole, however, considering the very few combinations of materials which experience has shown suitable for lower meter bearings, this section of the author's investigation brings out most forcibly the need of adequate lubrication.

The importance of surface cracking (Section 6) cannot be too strongly emphasized. As a result of much study both by the users of sapphire cup jewels and by the manufacturers, definite improvements have been made in the jewel structure, particularly at the surface; so that surface cracks are not as frequent as formerly.

The painstaking effort made by the author to isolate

and evaluate the influence of the separate factors being investigated is proved by the methods used, the results obtained, and the conclusions reached and stated, particularly in the Appendix.

I should like to make the following observations in regard to the author's work. (*a*) The possibility of rust-provoking oxygen being liberated from the sapphire itself is not supported, but rather is disproved, by the investigation. (*b*) The requirement of the presence of water vapour associated with oxygen in order to produce the commonly observed red oxide of iron was evident. (*c*) Both (*a*) and (*b*) remind us that oxygen and water are usually present in some degree, and for this reason the principal problem yet before us is to establish for the bearing elements the best protection possible against the action of oxygen and water vapour. In other words, an adequate lubricant having particularly the properties of permanence over a period of many years, ability to maintain a continuous protective film over the pivot surface, and a temperature characteristic which will ensure a normal functioning of the lubricant over a wide range of temperatures, seems at the moment to be the most necessary—and perhaps the most easily obtained—component of the ideal lower bearing.

Mr. V. Stott (*communicated*): The paper, perhaps inevitably, but I am sure not intentionally, gives the impression that I had expressed the definite opinion that the oxygen in the rust formed when a steel pivot rotates in contact with a sapphire jewel comes from the sapphire. About a year ago I wrote:* " I would, however, make it clear that in my original note in which I first published the above view on rust formation I stated:—†' It is not claimed that sufficient work has been done fully to establish the views now put forward, but it is suggested that they open up a new line of attack on problems of wear in pivot and jewel bearings which should repay further investigation.' Beyond this I do not wish to go at present. One very obvious critical experiment would be to run a steel pivot and sapphire jewel in an atmosphere of nitrogen, taking scrupulous care to exclude all traces of oxygen. Unfortunately, circumstances have so far prevented me from making this investigation."

The view was clearly put forward as a purely tentative one and as a basis for further investigation. That the investigation indicated was one well worth carrying out is shown by the results obtained by the author.

The experimental results described on pages 770 and 771 appear to conflict sharply with the statement on page 772 that the sapphire-steel and diamond-steel combinations gave the same rapid rate of production of oxide, and consequent increase in friction. Indeed, the author himself draws attention on page 771 to the difference in behaviour between the two units. Will he please explain further the statement on page 772?

The author refers to previous work of mine, and also quotes results of his own, showing that, by using sapphires of different orientation, most marked variations in the quantity of rust produced under otherwise identical conditions can be obtained. This fact, together with the difference in results obtained with a diamond-steel and a sapphire-steel combination, are inconsistent with the statement on page 772 that the phenomenon of rusting in the presence of oxygen and/or water vapour is independent of the sapphire. In view of the author's results it appears probable that the oxygen of the rust does not come directly from the sapphire; but the structure of the sapphire undoubtedly plays an important part in the phenomena of wear which result in the formation of rust.

Mr. G. F. Shotter (*in reply*): Mr. Lawson says that he would have liked me to have extended my experiments to other makes of meters. In some respects work as Mr. Lawson suggests would have increased the value of the results obtained, although tests which were carried out on other makes of meters confirmed the results given in the paper. When considering Mr. Lawson's point regarding varying load conditions, it has to be borne in mind that we are primarily concerned with the wear of the jewel and pivot at its running position at the lower loads. This takes place around the centre of the jewel, whereas the wear due to the higher loads takes place up the sides of the jewel owing to side thrust, and certainly does not affect accuracy at low loads, excepting possibly where the debris in dry jewels is carried into the centre.

Mr. Lawson raises the point of wear due to vibration. Only meters which had been in service for approximately the same time were used for the analysis. There are two components of wear in a bottom bearing, (1) rotational wear, and (2) wear due to parasitic forces, the former being a function of the revolutions and the latter a function of time. Both of these vary with the design of the meter.

Mr. Lawson mentions the possibility of using a dry lubricant, and quotes a case of debris produced by agate on sapphire. Our experience is that with a cleaned but worn and paired pivot and jewel, the friction is approximately the same as with an unworn pivot and jewel, and that the dry debris, particularly on a worn unit, produces a considerable increase in friction. In other words, the friction is entirely due to the combination of dry debris and the worn surfaces of the pivot and jewel. The important point to be noted is that if a pivot material can be chosen which produces a smaller quantity of debris under the same conditions, and which has the same or lower coefficient of abrasion than the ferric oxide, then that pivot material would be a better material to use than steel. That is to say, the product of the coefficient of abrasion multiplied by the quantity of debris produced under the same conditions should be as small as possible. I quite agree with Mr. Lawson's remarks on inverted jewels and I am of the opinion that they are inferior to the normal bearing. Finally, I should like to suggest to him that the reason he gets good results on single-phase and not on polyphase meters when using agate pivots, is increased weight.

I am very interested to note that Mr. Sandmeier is so much in agreement with the conclusions arrived at in the paper, and I am particularly interested in his microchemical investigation into the nature of the debris formed.

Mr. Hill remarks upon my temerity in suggesting that the oxygen comes from the sapphire. I can assure him

* *Watch and Clock Maker*, 1933, vol. 6, p. 91.
† *Journal I.E.E.*, 1932, vol. 70, p. 364.

that I had a perfectly open mind on the subject. The suggestion had been put forward, however, and it was obviously the first point to clear up with the results given in the paper. Apparently Mr. Hill is still doubtful regarding the impact experiment on diamond. From what we now know of the oxide production on diamond and sapphire, the impact experiment on diamond was not carried far enough to produce rust. This can be seen by comparing the number of impacts carried out on diamond and sapphire (Section 6) and the number of revolutions necessary to produce oxide in oxygen with these two materials. The "tickle" referred to by Mr. Hill is in reality a force of the order of several tons per square inch.

I agree with Mr. Hill regarding abrasion and burnishing in the case of diamond, and he will see that I mention this point on page 771. I am more than ever of the opinion that an investigation into this subject would prove to be of considerable value. Mr. Hill's remarks about the choice of a good material for bottom bearings are referred to in my reply to Mr. Lawson on this subject. In reply to Mr. Hill's query regarding the question on page 755 "Does oil prevent the formation of rust?" the question is obviously answered by the curve with an emphatic "No." In the light of the experiments described in Section (4), my view is that the use of oil decreases the rate of production of oxide, apparently in the ratio of about 30 to 1, other things being equal. This is due to the intimate contact between the sapphire and steel being broken during the greater portion of each revolution by the skating action of the pivot on the oil film. The other advantage of the use of oil or grease of the correct viscosity is to keep from the running circle the rust or debris formed. This point is the result of observation of thousands of oiled jewels returned from service, and it is only when the quantity of rust compared with the quantity of grease becomes very large that any serious increase in friction occurs between the jewel and pivot.

Mr. Hill asks how the factor of 30 is arrived at. This figure is the result of experiments on friction and is confirmed by Mr. Stott's figures given in the work entitled "An investigation of problems relating to the use of pivots and jewels in instruments and meters."* This is obviously only an approximate figure as this ratio will depend upon the viscosity of the oil, the quantity of oil, the optic axis, and the polish of the jewel.

The further information on the gas-filled units required by Mr. Hill is as follows:—

The nitrogen unit (No. 4) has done 240×10^6 revolutions and its speed has decreased by approximately 30 per cent. An examination showed the jewel to be rough in the centre with a very slight trace of black oxide with what appears to be sapphire dust.

The steel-steel unit has done 420×10^6 revolutions and the speed has increased by approximately 15 per cent. This unit is particularly interesting as, although the surface of the cup is no longer perfectly polished, no particles of the material appear to have been separated. The running surface of the cup, however, has been distorted or "rolled."

The steel-sapphire, vacuum unit has done 500×10^6 revolutions and the speed has decreased by approximately 30 per cent. An examination showed the jewel to be slightly worn in the centre, with what appeared to be sapphire particles distributed over the jewel, there being no sign of oxide. At some future date the complete results on these four units, including speed/time curves, will be issued in conjunction with the Electrical Research Association.

At the present juncture it is rather difficult to answer Mr. Hill's request for a more suitable material than steel for pivots, although in Section (5) of the paper he will certainly find some which should not be used. So far as our experiments have gone, tungsten certainly looks promising. From tests taken, it appears that the debris formed with tungsten does not seem so abrasive in its action as the ferric-oxide obtained with steel, but a good deal more work must be done before this matter can be decided.

The above remarks also apply to the sapphire-sapphire, on which, although in certain tests it has given fairly good results, further investigation is required.

We are at present carrying out a series of tests on pivots made from cane gramophone needles, with oil, and even these so far have given much better results than expected and certainly better than some dry sapphire-steel combinations.

With regard to Mr. Hill's last question, i.e. on the behaviour of a meter using a cleaned but worn pivot and jewel, I would refer him to Fig. 6 in the paper. I think it fully answers him. The results given in Fig. 6 sum up our experience over a number of years, that a cleaned but worn pivot and jewel will have a friction coefficient little different from that of a new pivot and jewel. By merely stating this I am not, however, by any means advocating the use of worn pivots and jewels, particularly the latter. In the first place, the rate of production of the rust will be very much greater than that of the polished surfaces of the new ones. Secondly, the friction caused by the debris on the worn pivot and jewel will be also greatly increased. One of the objects of the tests shown in Fig. 6 was to prove that the cause of the increase in friction was the highly abrasive action of the ferric oxide formed.

In reply to Mr. Felton, the object of the mechanism for producing surface cracks was to determine the possibility of producing such cracks by the impact forces to which a jewel is subjected during transport. This was the outcome of a very thorough investigation on some hundreds of jewels by the simple method described by him. As a matter of fact, several hundred unmounted jewels were examined for surface cracks, mounted, re-examined, and put into meters; they were then transported in the normal manner and again examined.

The subject of the production of surface cracks is not so simple as it appears. Apparently, it is governed by the method of mounting and also by the position in which the jewel is impacted relative to its optic axis.

When carrying out the tests on oil films I was aware that a very thin film of oil might become conducting, as mentioned by Mr. Felton. As he points out, however, this only makes the evidence for a film more conclusive, as we actually got a definite break. This also was one of the reasons for using such a low voltage across the contacts.

* *Collected Researches of the National Physical Laboratory*, 1931, vol. 24, p. 42.

I have never observed the condition of vaseline which Mr. Fawssett mentions, but we used it in order to simulate the conditions of an oil, originally of low viscosity, which had attained the consistency of vaseline after several years' use.

Sangamo oil and the so-called medicinal paraffins are in the same group as the ordinary lubricating oils, and it appears that when either of these are used their viscosity increases with time and also with exposure to the air.

I agree that Sangamo oil and even some of the medicinal paraffins are not viscous enough, owing to the fact that with low-viscosity oils any oxide produced settles in the bottom of the cup, whereas with an oil having a higher viscosity, such as vaseline, the debris is diffused and does not settle.

This effect is shown in Fig. 10 and also by the photomicrographs, Figs. 2 and 3. It was to bring out this point that the tests shown by d and e in Fig. 10 were carried out, and I do not think that any of the paraffin series would have altered the results to any appreciable extent.

The load history of the pivot and jewel shown in curves (*a*), (*b*), and (*c*), in Fig. 10 did not exceed 5 per cent, the running position of the pivot being the centre of the jewel.

The question of cleaning jewels with trichlorethylene has been answered by Mr. Cheetham's remarks on the paper. This also applies to Mr. Fawssett's request for rotational tests in oil with a "metallic" jewel.

From our examination of the condition of the jewels, I do not think that there is very much in the point raised that, in the tests shown in Section (5), the meters were normally running at a higher load than the testing load, thereby giving a too optimistic result. Indeed, it is quite conceivable that where a larger amount of wear has taken place the results might be too pessimistic at the load at which the meters were tested.

The shaft movement is approximately 0·007 in. and the "point of contact" movement is 0·011 in.

The sapphire-steel combination with oildag unit has now done 17×10^6 revolutions and the results are the same as shown in the paper (see Fig. 13) at the 10×10^6 point.

It is possible that the colour of the debris in the platinum-sapphire combination is modified by the particles of the jewel, but there is no doubt that the oxide of the pivot material is the predominant colour. In the light of the experiments carried out on the enclosed units, I find it a little difficult to understand why Mr. Fawssett still clings to the view that the oxygen comes from the sapphire, although he considers that a catalyst is necessary. For instance, take two of the tests, the vacuum unit, which to date has done 500×10^6 revolutions and shows no sign of any oxide, and the test with steel-sapphire in dry oxygen where black oxide of iron was produced in large quantities. Unless Mr. Fawssett thinks that dry oxygen acts as a catalyst, I fail to see how he can reconcile these results with the view that the oxygen is obtained from the sapphire to produce rust.

In the case of the test in Section (6) on the diamond, it is my opinion that the debris formed was steel dust, similar to that which appears to form on a sapphire jewel before rust is visible.

It is difficult to answer Mr. Fawssett's question as to whether the oxygen and hydrogen in the oxygen-hydrogen unit (page 770) combine under intense pressure to form water vapour. My own view, as stated in the paper, is that for a solution to the problem we have to look at the extreme activities of the particles of metal torn off under the high pressure.

I certainly agree with Mr. Cheetham with regard to the light rotor. It is not always appreciated that the heavy rotor not only produces the greater amount of debris for the same number of revolutions in a given time, but that it also produces a greater error in the meter due to the increased weight, i.e. the total error produced is compounded.

I am glad Mr. Cheetham points out that a correct perspective of the matter was wanted. This was one of the points that I wished to emphasize, my opinion being that the perspective has been largely distorted by engineers who have not oiled their jewels. I also agree with him about the importance of a clean top bearing and I can assure him that every care was taken on this point in these tests.

Regarding the existence of an oil film, I am not so certain that all mechanical engineers agree that no oil film can exist under these high pressures. In the discussion on Mr. Lawson's paper* I said:—

"The following extract from *Oil Power* (U.S.A., February, 1929) is interesting on the point of the existence of oil between the surfaces of contact: '*The lubrication of ball bearings.*—Lubrication plays a very essential part in a ball bearing. In spite of the fact that the principle of the ball bearing is a rolling one, in the most perfect bearings a sliding action exists. This means friction and the friction must be overcome by the use of oil. There is need for lubrication both between the ball and the path in which it rolls and between the ball and the separator. The presence of a lubricant at these points renders almost negligible what amount of friction there is. *It may seem improbable, yet there is an actual film of lubricant between the surfaces of contact, provided the lubricant is of proper quality.*' "

As far as I can see, the conditions with a ball bearing are for all practical purposes equivalent, as far as pressure on the point of contact of the ball is concerned, to those which exist in a meter. I still feel that this film exists, particularly when the pivot is in motion. On the other hand, as rust is produced even with oiled bearings, there certainly seems room for a modification of the theory that an oil film exists all the time, to the extent that partial filming does take place at certain periods. I am at present carrying out further tests in an attempt to shed more light on this subject. Another point to be borne in mind regarding the difficulty of proving the existence of the oil film by friction tests is the masking of this decrease of friction which is assumed would take place if a film were present, by the "cohesive drag" of the oil.

I am certainly not prepared to agree at present with Mr. Cheetham's second piece of evidence in favour of non-filming, i.e. that if air could not get in oil also could not do so.

* *Journal I.E.E.*, 1929, vol. 67, p. 1147.

Mr. Cheetham's experiments on impact are very interesting and I wish he had given us some more information on his tests.

Regarding the difference between natural and synthetic stones, my experience with natural stones is practically negligible.

Mr. Cheetham raises the point of the rusting of spring-supported jewels through using steam for cleaning. In the first place very few of our jewels are spring-seated, but as we also clean pivots by the same methods we should have observed any rusting that might have taken place. I am glad that Mr. Cheetham mentioned this point, as the indiscriminate use of steam may lead to bad results.

We have adopted the following procedure. The jewel and pivot to be cleaned are first placed on a suitable hot-plate kept at approximately 212° F. They are then cleaned with steam and are again placed on the hot-plate and allowed sufficient time to dry right out. So far this method has given excellent results.

Regarding Section (7), the polarized-light method was the only one at our disposal, and for our purpose it was sufficiently accurate. However, I entirely agree with Mr. Cheetham's remarks on the subject. From some results recently obtained it certainly appears that orientation is not the only factor determining wear.

Mr. Page makes the statement that there is no fundamental difference between the jewel problem in an electricity meter and the problem of turbo-alternator bearings. My view is that it is purely a matter of degree and that no fundamental difference does exist.

Mr. Page also refers to Section (7) of the paper. I should like to point out that the reason the tests were taken was the hypothesis put forward that the rust was caused by oxygen obtained from the sapphire, or, to paraphrase Mr. Page's remarks, that sapphire was a compound having an oxygen content, i.e. Al_2O_3. I am extremely interested in Mr. Page's hypothesis, but I am of the opinion that considerable theoretical and practical work is required before it can be accepted.

I quite agree with Mr. Everett that the sensitivity of the test for detecting oxygen and/or water vapour is very high. This point is very strongly brought out by the recent examination of the nitrogen unit, which after 240×10^6 revolutions showed a very slight trace of black oxide.

Mr. Batt seems to have misunderstood the object of the impact test given in Section (6). The object was to obtain some information on the production of surface cracks on sapphire jewels due to transportation. The $\frac{1}{16}$ in. mentioned was taken as the approximate limit of travel between the top and bottom bearings.

From some tests which we have carried out on the subject of wear due to vibration, I am of the opinion that the major cause of wear is rotation. As pointed out in my reply to Mr. Lawson, this depends on the ratio of the time that the meter is in service to the number of revolutions completed in that time, and also upon the design of the meter.

In reply to Mr. Stott, I hasten to assure him that I had no wish to give the impression that his definite opinion was that the oxygen in the rust formed with a steel-sapphire combination came from the sapphire. I, like Mr. Stott himself, considered it as a possible line of attack on the phenomenon of wear.

I am indebted to Mr. Stott for pointing out the apparent conflict in the statements on pages 770, 771, and 772. My remarks on page 772 as to the rapid increase in friction should only apply to the steel and not to the diamond as explained on pages 770 and 771, although the diamond element stopped due to formation of oxide after 54×10^6 revolutions. This test was concluded after the reading of the paper.

I am afraid that Mr. Stott has misunderstood my meaning when he disagrees with my statement that " the phenomenon of rusting in the presence of oxygen and/or water vapour is independent of the sapphire." What I intended to convey was that with, say, a steel pivot rusting will take place whether the cup is of sapphire, steel, diamond, agate, or any other material, and that rusting is not particularly confined to the sapphire.

We both agree that the rate of production of rust will vary with certain characteristics of the sapphire, i.e. optic axis, polish, etc.

I quite agree with Mr. Ockenden that there is considerable difficulty in deciding the nature of the debris from observation of colour. On the other hand, with the different materials which we have used for pivots the colour of the deposit has generally been related to the colour given for the oxide of this material. Mr. Ockenden's investigation on the diamond jewel is very interesting, although I would refer him to my reply to Mr. Fawssett on this subject of a catalyst being required for the production of an oxide.

My only knowledge regarding the hardness of stellite was the great difficulty experienced in working this material. Perhaps a better description for the material is " tough." I should like to call Mr. Ockenden's attention, however, to the behaviour of the material when run dry.

Mr. Scott Lynn mentions a point of particular interest to me; it fills in one of the important gaps in the paper on rust production, i.e. the production of rust in meters equipped with diamond-steel bearings. This strengthens the view that the oxygen for rust production does not come from the material of the sapphire. I think his remarks regarding the rusting of pivots due to other causes than wear are extremely valuable. They show how necessary it is to ensure that the handling of the bearings and oil before use is carried out with extreme care.

Mr. Scott Lynn's theory of surface cracking, which he refers to as appearing as minute half-moons, is interesting. What we call surface cracks appear as straight lines, there usually being several in the same plane. These are observed on both new and old jewels. On the other hand, what he describes as half-moons we have observed on worn jewels, generally up the wall of the jewel, and we have assumed that these were due to wear taking place at the higher loads. There is a possibility, of course, that they may have been started by surface cracks.

I confirm Mr. Scott Lynn's statement as to the difficulty of observing surface cracks; whether they are visible or not depends largely on the method of illumination used in the microscope.

I have no doubt that his theory regarding the cutting effect of the surface cracks is correct. Mr. Sandmeier has always emphasized the danger of using jewels with surface cracks, particularly as there is a possibility of the pivot picking up small pieces of sapphire off the edge of these surface cracks and acting as a cutting tool. This is, of course, the objection to the use of a needle for testing jewels.

Mr. Martin's contribution is particularly valuable as it can be taken to express the American point of view on the problem.

In answer to his remarks on Section (1), the length of service of the meter was, as stated in the paper, between 7 and 8 years. Regarding Section (7), my opinion, as stated, is that a suitable grease would be more satisfactory, for, as described in the paper, the ultimate condition of the low-viscosity oil is a grease and it appears that this is the ideal state for the lubricant to be in.

It would appear from Mr. Martin's figures on temperature variation that conditions in America must be much more severe than those experienced in this country, and, consequently, the type of grease used would have to be governed by these conditions.

The tests on oil film were carried out at approximately 60° F. only.

In reply to Mr. Martin's point about the initial drop shown in the majority of the curves in Section (5), all the pivots had a diameter of 0·05 in., this being the diameter of the standard steel pivots used in all the tests described in the paper. These " droops " are due to the stabilization of the pivot radius, i.e. the fact that in the softer material the elastic limit was reached with the initial radius, deformation wear taking place until the radius or area of contact was sufficient to support the weight without further deformation. Consequently, it would appear that this " droop " could be eliminated by increasing the diameter or pre-shaping the pivot to suit the jewel radius.

I am pleased to note the emphasis that Mr. Martin lays on the problem of surface cracks. We have, however, noted that there has been improvement in this direction in recent years.

In conclusion, with regard to Mr. Martin's remarks on Section (7), I should like to emphasize the necessity of providing a jewel holder which will retain a large quantity of grease so that the products of wear are easily diffused.

AN ELECTROMAGNETIC METHOD FOR MEASURING YOUNG'S MODULUS FOR IRON, STEEL, AND NICKEL RODS.*

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(*Paper first received* 13*th December*, 1933, *and in final form* 16*th February*, 1934.)

Summary.

If a rod of iron, steel, or nickel, is placed axially in a solenoid which is excited by direct current, and if the rod is caused to vibrate longitudinally with its natural frequency, the changes of mechanical stress will produce corresponding changes of flux in the rod, so that an e.m.f. of the same frequency will be induced in a search coil which embraces the magnetized part of the rod. The frequency of this e.m.f. is measured by means of oscillograms, from which the value of Young's modulus is easily found.

Introduction.

It has been known for many years that a definite relationship exists between the stress and the permeability of iron, steel, nickel, and also cobalt wires. Joule† appears to have been the first to observe that a bar of iron changes its length when magnetized, and Shelford Bidwell‡ carried out a large number of exact researches in this connection in which he measured the changes of length of wires when placed in a magnetic field both when the wire was loaded and when it was unloaded. R. L. Sanford† measured the change of permeability of a steel wire due to loading.

The question has been raised whether the elasticity of a steel or iron wire is affected by magnetization. Results obtained by Wertheim and Wartmann‡ showed that they could observe no such effect. Kimball and Piazzoli,§ however, found that the breaking tension of iron wires is increased by longitudinal magnetization, the former putting the increase at 0·9 per cent when the wire is magnetized to saturation.

A distinction is to be made between the values of Young's modulus as found by static and by kinetic methods respectively. In the static method the strains are isothermal, whilst in the kinetic method the strains are adiabatic. Values of Young's modulus obtained by Wertheim by a vibrational method were found to be generally greater than the values found by direct statical extension, and the differences are much greater

* The Papers Committee invite written communications, for consideration with a view to publication, on papers published in the *Journal* without being read at a meeting. Communications, except those from abroad, should reach the Secretary of the Institution not later than one month after publication of the paper to which they relate.

† *Philosophical Magazine*, 1847, vol. 30.

‡ *Proceedings of the Royal Society*, 1886, vol. 40, p. 109; 1890, vol. 47, p. 469.

† *Electrical World*, 1925, vol. 86, p. 309.

‡ "Encyclopædia Britannica," 9th ed., vol. 15, p. 270 (article on "Magnetism").

§ "Encyclopædia Britannica," *loc. cit.*

than those which would be predicted from the heating and cooling effects due to contraction and elongation. Sir W. Thomson (Lord Kelvin) considered that the discrepancies were due to errors of observation in the vibrational method as used by Wertheim.*

It appeared to the author† that the phenomenon of the change of magnetic permeability with change of strain (usually referred to as the magneto-striction effect) could be used for measuring the frequency of longitudinal vibration of a wire of iron, steel, or nickel, and consequently would lead to a method for determining the corresponding values of Young's modulus.

In what follows, a brief account of this method will be given, together with the results of a number of measurements of the values of Young's modulus for wires of iron, steel, and nickel, respectively.

Details of the Solenoid and Search Coil Used in the Tests.

The wire under test was supported symmetrically in a long solenoid which was excited by direct current. Arranged at the central part of the solenoid and embracing the wire was a search coil of 50 000 turns of fine wire. The search coil was connected through a valve amplifier to an oscillograph. The inclusion of the valve amplifier made it possible to operate the oscillograph without taking any appreciable current from the search coil.‡

The wire could be set in a state of longitudinal vibration either by drawing a piece of resin-coated leather along its surface or, alternatively, by means of a gentle tap applied to one end.

The main details of the solenoid used are as follows. There are 6 layers of No. 16 S.W.G. double cotton-covered copper wire giving a total of 2 270 turns. The mean length of the winding is 91·2 cm, so that the number of turns per cm length is 24·9. The inside diameter of the winding is 7·6 cm and the outside diameter is 11·5 cm.

From actual ballistic tests made by means of suitable search coils it was found that the average value of the magnetizing force (H) which is produced over the cross-section at the central part of the solenoid is related to the magnitude of the exciting current by the expression $H = 29 \cdot 7I$.

When the solenoid is excited and the wire under test is set in a state of longitudinal vibration the consequent extension and compression of the wire produces corresponding changes in the permeability, so that the flux which is linked with the search coil changes and an e.m.f. is developed which is of the same frequency as that of the vibrations of the wire. If an oscillographic record is taken of the e.m.f. which is induced in the search coil and if simultaneously a photographic record is taken of a wave of known frequency, a time scale is obtained and the frequency of the induced e.m.f. in the search coil and consequently the frequency of the vibrations of the wire can be determined.

The value of the magnetizing force for which the action is most sensitive is about 50 oersteds for hard-

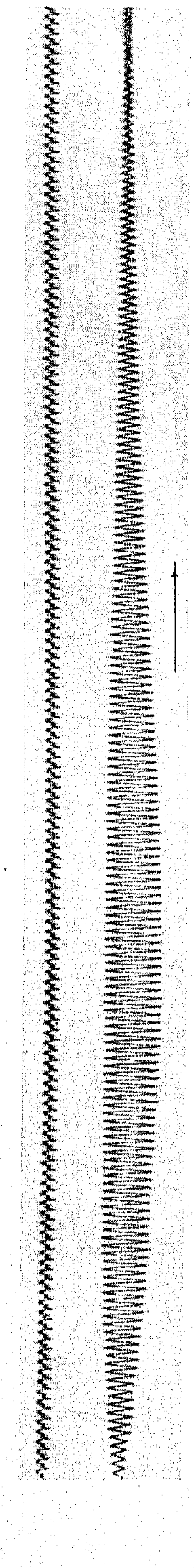

Fig. 1.—Armco iron, ¼ in. diameter. Clamped at one end; free vibrating length, 199·5 cm; frequency of longitudinal vibration, 646; frequency of timing wave, 500.

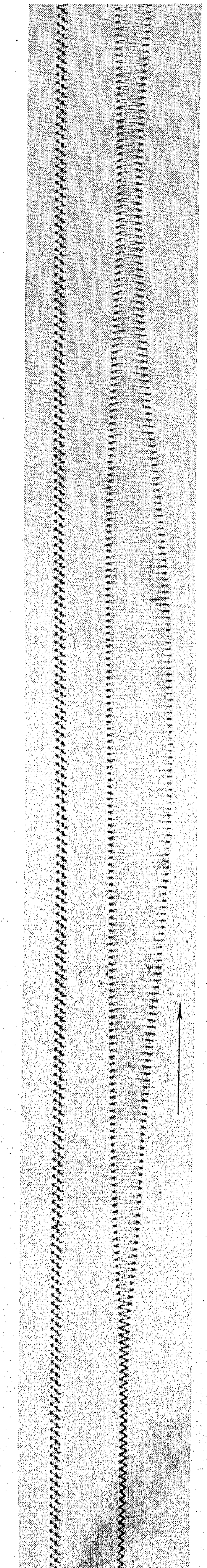

Fig. 2.—Pure nickel rod, ¼ in. diameter. Clamped at one end; free vibrating length, 200·5 cm; frequency of longitudinal vibration, 635; frequency of timing wave, 500.

* "Encyclopædia Britannica," 9th ed., vol. 7, p. 815 (article on "Elasticity").
† *Nature*, 1933, vol. 131, p. 351.
‡ E. L. E. Wheatcroft and A. Graham: *Engineering*, 1930, vol. 130, p. 671; W. Jackson: *Wireless Engineer*, 1934, vol. 11, p. 64.

drawn steel wire and a smaller value for soft iron. Good results, however, may be obtained for a wide range of values of H, and the remanence alone will often give a sufficiently large amplitude for the induced e.m.f. wave.

For the time wave a standard tuning fork was used having a frequency of 500, the vibration being maintained electrically in the well-known manner. In this way the frequency of vibration of the rod could be measured with an error of less than 1 per cent.

Formulæ for the Natural Frequency of Longitudinal Vibrations of an Elastic Wire.

(i) If a wire is clamped at one end the natural frequency of longitudinal vibration is given by the expression $f = c/(4l)$ vibrations per sec., where c is the velocity of sound in the wire in cm per sec. and l is the free length of the wire in cm.

Since the velocity c is related to Young's modulus (E) and the density (ρ) of the wire by the expression $c^2 = E/\rho$, the formula for the natural frequency of vibration of the wire may be written

$$f = \frac{1}{4l}\sqrt{\left(\frac{E}{\rho}\right)} \text{ vibrations per sec.}$$

where E is expressed in dynes per cm² and ρ is the density in g per cm³.

It follows, therefore, that

$$E = \rho(4fl)^2 \text{ dynes per cm}^2$$
$$E = 14\cdot5 \times 10^{-6} \times \rho(4fl)^2 \text{ lb. per sq. in.}$$

(ii) If the wire is clamped at both ends or is free at both ends, the natural frequency of longitudinal vibrations will be given by the expression $f = c/(2l)$ vibrations per sec., so that, in this case,

$$E = \rho(2fl)^2 \text{ dynes per cm}^2$$

or

$$E = 14\cdot5 \times 10^{-6} \times \rho(2fl)^2 \text{ lb. per sq. in.}$$

Results of the Tests.

(i) *Armco Iron.*

This material is a very pure form of commercial iron and may be taken as representative of unalloyed iron. A rod of this material, ¼ in. diameter as drawn, was obtained and arranged in the solenoid, being firmly clamped at one end. The free length of the rod was 199·5 cm. The oscillogram of the longitudinal vibrations is shown in Fig. 1, and the frequency is found to be 646 cycles per sec. The density of the iron is 7·85, so that

$$E = \rho(4fl)^2 = 20\cdot9 \times 10^{11} \text{ dynes per cm}^2$$
$$= 30\cdot3 \times 10^6 \text{ lb. per sq. in.}$$

(ii) *Mild Steel.*

For this test a rod of bright drawn mild steel, ¼ in. diameter, was used. The rod was clamped at one end, and the free length was 199 cm.

From the oscillogram of the longitudinal vibrations it was found that the frequency was 650 cycles per sec. From these results the value of Young's modulus was calculated and the value so obtained is given by

$$E = \rho(4fl)^2 = 21\cdot15 \times 10^{11} \text{ dynes per cm}^2$$
$$= 30\cdot65 \times 10^6 \text{ lb. per sq. in.}$$

A test was also carried out on a mild steel wire, 0·092 in. diameter, clamped at both ends, the free vibrating length being 230·5 cm. From the oscillogram obtained the frequency of the longitudinal vibrations was found to be 1 086 cycles per sec., so that the value of Young's modulus is

$$E = \rho(2fl)^2 = 19\cdot9 \times 10^{11} \text{ dynes per cm}^2$$
$$= 28\cdot8 \times 10^6 \text{ lb. per sq. in.}$$

(iii) *Hard-Drawn Steel Wire.*

A length of hard-drawn steel wire as used in the manufacture of colliery winding ropes was tested. The diameter of the wire was 0·122 in. The wire was clamped at both ends, and the free vibrating length was 231 cm. From the oscillogram the frequency of the longitudinal vibrations was found to be 1 104 cycles per sec., and the value of Young's modulus is accordingly obtained as

$$E = \rho(2fl)^2 = 20\cdot6 \times 10^{11} \text{ dynes per cm}^2$$
$$= 30\cdot0 \times 10^6 \text{ lb. per sq. in.}$$

(iv) *Nickel.*

For this test a hardened rod of pure nickel, ¼ in. diameter and of density 8·9, was clamped at one end, the free vibrating length being 200·5 cm. From the oscillogram reproduced in Fig. 2 the frequency of longitudinal vibrations is found to be 635 cycles per sec., so that the value of Young's modulus is

$$E = \rho(4fl)^2 = 23\cdot1 \times 10^{11} \text{ dynes per cm}^2$$
$$= 33\cdot5 \times 10^6 \text{ lb. per sq. in.}$$

The investigation was carried out in the Electrical Engineering Department of the University of Sheffield.

THE TIME-DECREASE OF PERMEABILITY AT LOW MAGNETIZING FORCES.*

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(*Paper first received* 23*rd September*, 1933, *and in final form* 12*th March*, 1934.)

SUMMARY.

It has been found that in both normal and incremental permeability measurements the values obtained at low flux densities are increased by the application of a large magnetizing force, such as is involved in the demagnetization of a specimen, this increase then disappearing approximately exponentially with time. This effect, which occurs whether d.c. or a.c. methods of measurement are used, is termed the "time-decrease of permeability." It appears to be due to a disturbance of the material from its equilibrium condition by a strong magnetizing force, the time-decrease representing a gradual return to its equilibrium state, which may require several days or even weeks to be effectively completed. A similar disturbance can be produced by severe mechanical treatment.

The time-decrease is only considerable below about $B = 1\,000$, and within that range varies greatly with the magnetizing force. It also depends enormously on the nature of the material tested, being much greater in high-silicon alloys than in any other type of material. Except at vanishingly small magnetizations, the magnetizing force applied in making the measurements itself exerts a disturbing influence and affects the magnitude of the time-decrease. The effects of a polarizing magnetization and of high temperature have also been examined.

Some correlation appears to exist between the magnitude of the time-decrease and the shape of the μ/H curve, but it has not been found possible to establish a quantitative correspondence with any function derived from the μ/H curve. A good mathematical representation of the variation of the permeability with time is given by an expression of the form $\delta = K\epsilon^{-At^n}$, where K, A, and n are constants.

The time-decrease is shown to be distinct from ordinary ageing, although the results obtained by Wild and Perrier indicate a close relation between the two phenomena. The practical significance of the effect is discussed in relation to the constancy of inductance of iron-cored coils and to the standardization of the conditions of permeability measurements at low flux densities.

INTRODUCTION.

In recent years, owing to the extensive use of magnetic materials under superposed direct and alternating magnetizations (for example, in audio-frequency transformers and reactances), the determination of the incremental permeability of such materials has become of considerable importance.

The incremental permeability, μ_Δ, is defined as the value of $\Delta B/\Delta H$, where ΔH is a cyclic variation in the magnetizing force applied to the material and ΔB is the resulting change in the flux density. Under these conditions of magnetization the material may be regarded as being carried round an assymetrical hysteresis loop, as shown in Fig. 1, superimposed on a larger

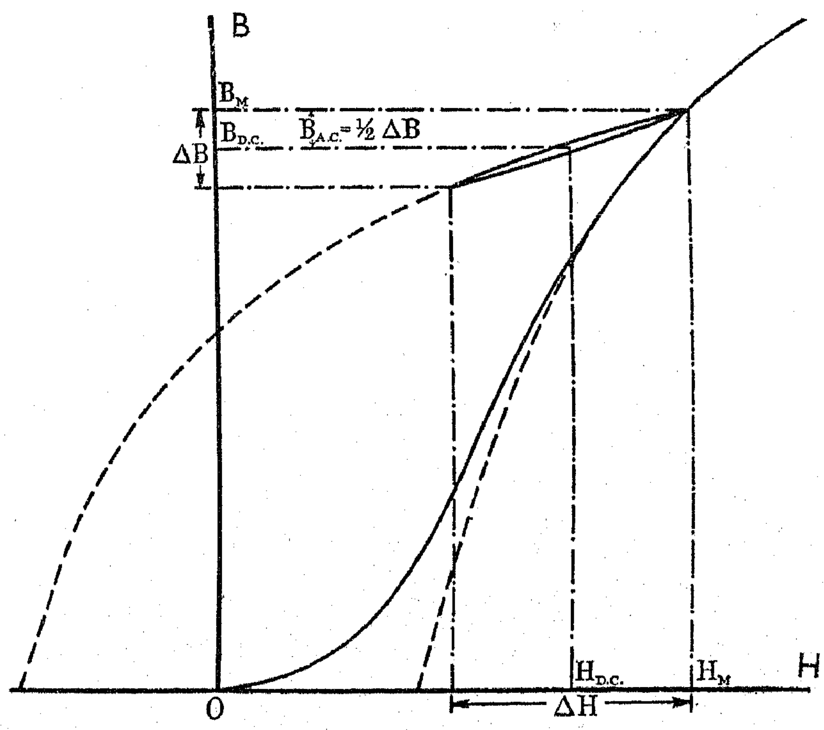

FIG. 1.—Unsymmetrical hysteresis loop.

symmetrical loop corresponding to a maximum flux density, B_M, which is the greatest flux density reached during the cycle of magnetization. The incremental permeability is given by the slope of the line joining the tips of the subsidiary hysteresis loop, and is clearly dependent on (i) the maximum flux density (B_M) and (ii) the range of flux density (ΔB).†

In making measurements of incremental permeability some years ago, the authors observed that the values obtained were liable to vary considerably with time. The procedure adopted was to apply the polarizing d.c. magnetization, to reverse this several times in order to bring the material into a cyclic condition, and finally to adjust the alternating magnetization to produce the desired value of ΔB. If then a series of measurements were made after successive short time-intervals it was

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† See References (1) and (2).

found that the incremental permeability decreased with time from its value immediately after the reversals of the d.c. magnetization according to some exponential law. A fresh reversal of the d.c. magnetization restored the incremental permeability to its previous higher value.

Investigation showed that a similar effect occurred in normal permeability measurements at low flux densities. After demagnetization by the customary method of reversals from a high magnetizing force, a gradual decrease in permeability with time was found which persisted for several days or even weeks before an appreciably constant value was reached.

Similar changes of permeability with time had been previously noted by Campbell,* Wild and Perrier,† Steinhaus,‡ and Goldschmidt.§

The variations in permeability obtained by the authors on certain specimens appeared to be much greater than any previously recorded, and as no very thorough investigation of the effect had been made a detailed examination was undertaken. A preliminary note on the earlier results obtained was published in 1931,‖ and the work therein described was subsequently much extended. In 1932 an account of "Time-disaccommodation of small symmetrical and unsymmetrical cycles" was published by Atorf,¶ many of whose observations closely parallel those made by the authors, although his approach to the subject differed somewhat from theirs.

There is considerable diversity in the terminology employed by various investigators, the effect being described as "time after-effect," "rejuvenation," and "time-disaccommodation effect." The use of "time after-effect" in this connection seems undesirable, since a quite distinct phenomenon—the tendency for the flux density to approach its stable value only gradually after a change in the magnetizing force—has been generally known as "magnetic after-effect" by analogy with the similar "after-effects" occurring when a material is stressed mechanically or when a dielectric is subjected to an electrical potential difference.

Wild and Perrier** used the term "rejuvenation" for the increase in permeability after demagnetization because they considered that the subsequent decrease was essentially the same as the "ageing" effect occurring after a high-temperature treatment. Ageing, however, is generally held to result, at least in part, from changes in the metallurgical constitution of the material, which can hardly be involved in the decreases of permeability now under consideration since the original values can be reproduced merely by applying suitable magnetic treatment. It seems preferable, therefore, to use different terms to refer to the two effects.

The remaining description, "time-disaccommodation effect," which appears to be the most favoured in the German literature on the subject, is clumsy in English and provides no precise information as to the nature of the underlying mechanism of the effect. It seems preferable, therefore, to adopt a simple descriptive label and to refer to the effect as the "time-decrease of permeability."

* See Reference (3).
† *Ibid.*, (4).
‡ *Ibid.*, (5).
§ *Ibid.*, (6).
‖ *Ibid.*, (7).
¶ *Ibid.*, (8).
** *Ibid.*, (4).

METHOD OF EXPERIMENT.

A wide range of specimens was tested, including both laminated and solid materials of various compositions and magnetic qualities. A list of all the specimens used, with particulars of their dimensions, etc., is given in Table 1. All the specimens were of ring form and most of them had received no heat treatment for several years previously, and could therefore be regarded as thoroughly aged; where recent heat treatments had been applied, information concerning these is given in the table. In all tests on laminated samples precautions were taken to avoid mechanical stresses due to the windings by enclosing the rings in thin, concentric ebonite tubes, as described in a previous paper.*

The tests carried out comprised measurements of normal permeability with d.c. or a.c. magnetization and of incremental permeability with superposed d.c. and a.c. magnetizations, at various time-intervals after the application of a given magnetic or other treatment.

The d.c. tests were made by the ballistic method, and the a.c. tests, which were only applicable to the laminated specimens, by the Campbell mutual-inductance bridge.†

In the ballistic tests the sensitivity obtained was such that a reversal of $B = 10$ in the specimen produced a deflection of 200 mm. The procedure was to demagnetize the specimen, adjust to the desired value of H, reverse the magnetization a fixed number of times to bring the material into a cyclic state, and measure the permeability after leaving the specimen until a given time had elapsed.

In the a.c. bridge method the permeability could easily be measured to 2 parts in 1 000 when the magnetizing force, H,‡ was 0·001 C.G.S. units (oersteds). In these tests the desired alternating magnetizing current was first obtained, the specimen was then demagnetized from approximately $H = 5$ by reversals of a diminishing direct current, the a.c. magnetization was switched on again, and the bridge was adjusted to balance and kept in balance as closely as possible. A high resistance (1 000 Ω) was placed in series with the magnetizing winding to keep the current sinusoidal.

Besides being more sensitive than the ballistic method, the a.c. method was more convenient in that the minimum time-interval after the completion of demagnetization at which permeability measurements could be made was shorter and the results were less subject to disturbance from other time effects. Further, as the readings in the a.c. method are proportional to μ instead of B, they cover a smaller numerical range and may be obtained with fewer changes of calibration, while small inaccuracies in the setting of H occasion much less error in the results.

In the measurements of incremental permeability the Campbell bridge method was again used, a large inductance being connected in the d.c. magnetizing circuit to minimize the induction of alternating current in it by the alternating flux. It was found that, except at very small polarizing magnetizations, the application and reversal of the d.c. magnetization wiped out the time-decrease of permeability that had occurred since the

* See Reference (9).
† *Ibid.*, (10).
‡ In all a.c. measurements the values of H and B quoted are maximum values.

previous demagnetization; and in the incremental permeability measurements, therefore, the time was reckoned from the final reversal of the d.c. magnetization.

In all the measurements, owing to the variation of the permeability with time, it was practically impossible to maintain the flux density constant. All tests were therefore made with a constant magnetizing force.

(2) *Variation of Time-decrease with Magnetizing Force and Material Tested.*

The magnitude of the time-decrease was found to differ greatly in different materials and to vary enormously in the same specimen with the magnetizing force at which the measurements were made. A simple method of determining its variation with H was to obtain two permeability curves, one immediately after demagnetization and the other after a considerable period, say 2 weeks.

TABLE 1.

List of Specimens Tested.

No.	Material	Condition	Approximate density	Dimensions: Mean diameter	Dimensions: Cross-sectional area	Heat treatment
				cm	cm²	
1	Low-carbon steel	Solid	—	10·5	4·4	—
2	Armco iron	Solid	—	7·5	0·5	Annealed at 950° C.
3	Transformer iron	Laminated	7·8	23	7·6	—
4	Electrical iron	Laminated	7·8	13·5	1·75	Annealed at 950° C.
5	Electrical iron (Lohys)	Laminated	7·8	13·5	1·9	—
6	Electrical iron (Special Lohys)	Laminated	7·8	13·5	1·4	—
7	Low-silicon iron	Laminated	7·7	13·5	1·0	—
8	Low-silicon iron	Laminated	7·7	5	1·8	Annealed
9	Low-silicon iron	Laminated	7·7	5	1·6	Annealed at 1 000° C.
10	50 per cent nickel-iron	Laminated	8·15	13·5	2·5	—
11	Swedish iron	Solid	—	12·5	1·0	—
12	High-silicon iron	Laminated	7·55	13·5	1·0	—
13	High-silicon iron	Laminated	7·55	8·8	1·85	—
14	High-silicon iron	Laminated	7·55	13·5	2·6	Annealed
15	High-silicon iron	Laminated	7·55	13·5	2·5	—
16	High-silicon iron	Laminated	7·55	13·5	1·4	Annealed
17	High-silicon iron	Laminated	7·55	5	1·7	—
18	High-silicon iron	Laminated	7·55	13·5	1·1	—
19	High-silicon iron	Solid	7·55	12·5	1·0	Annealed
20	Aluminium iron	Solid	—	6·5	1·0	—
21	Mumetal	Spiral strip	8·60	8·0	3·7	—

EXPERIMENTAL RESULTS.

(1) *Curves of Time-decrease of Permeability.*

Curves showing the way in which the permeability diminished with time after the specimen had been demagnetized were obtained on various materials. A typical example of these curves is given in Fig. 2, curve 1. The decrease of permeability is very rapid during the first few minutes and is still considerable at the end of 2 hours. More prolonged tests showed that a perceptible decrease of permeability continued in many specimens for about 2 weeks. The time-decrease curves for a.c. and d.c. magnetizations were precisely similar in shape.

The time-decrease of incremental permeability is illustrated by the curves in Fig. 3, which were obtained with a fixed value of ΔH and a series of values of d.c. magnetization. It is apparent that as the d.c. magnetizing force increases the time-decrease steadily diminishes, and above $B_{D.C.} = 12\,000$ it practically disappears.

All the curves of time-decrease were closely repeatable.

Then, if μ_I, μ_F are the "immediate" and "final" permeabilities respectively, the magnitude of the time-decrease (D) may be conveniently expressed as a percentage of the final permeability, i.e. by $100(\mu_I - \mu_F)/\mu_F$.

To allow sufficient time for the requisite adjustments to be made under the most difficult conditions, the "immediate" readings were generally taken 2 minutes after the completion of demagnetization, although in favourable circumstances they could be obtained within 30 sec. or even less. The values of μ_I are not, therefore, the highest values attained by the permeability, and the values of D given in the tables and curves are less than the actual total time-decreases. In determining the "immediate" permeability curve it was, of course, necessary to demagnetize the specimen afresh before each reading.

A typical curve showing the way in which the time-decrease, D, varied with the magnetizing force is given in Fig. 4 (curve 1). The time-decrease, although only 10 per cent at $H_{max.} = 0·1$, did not become entirely

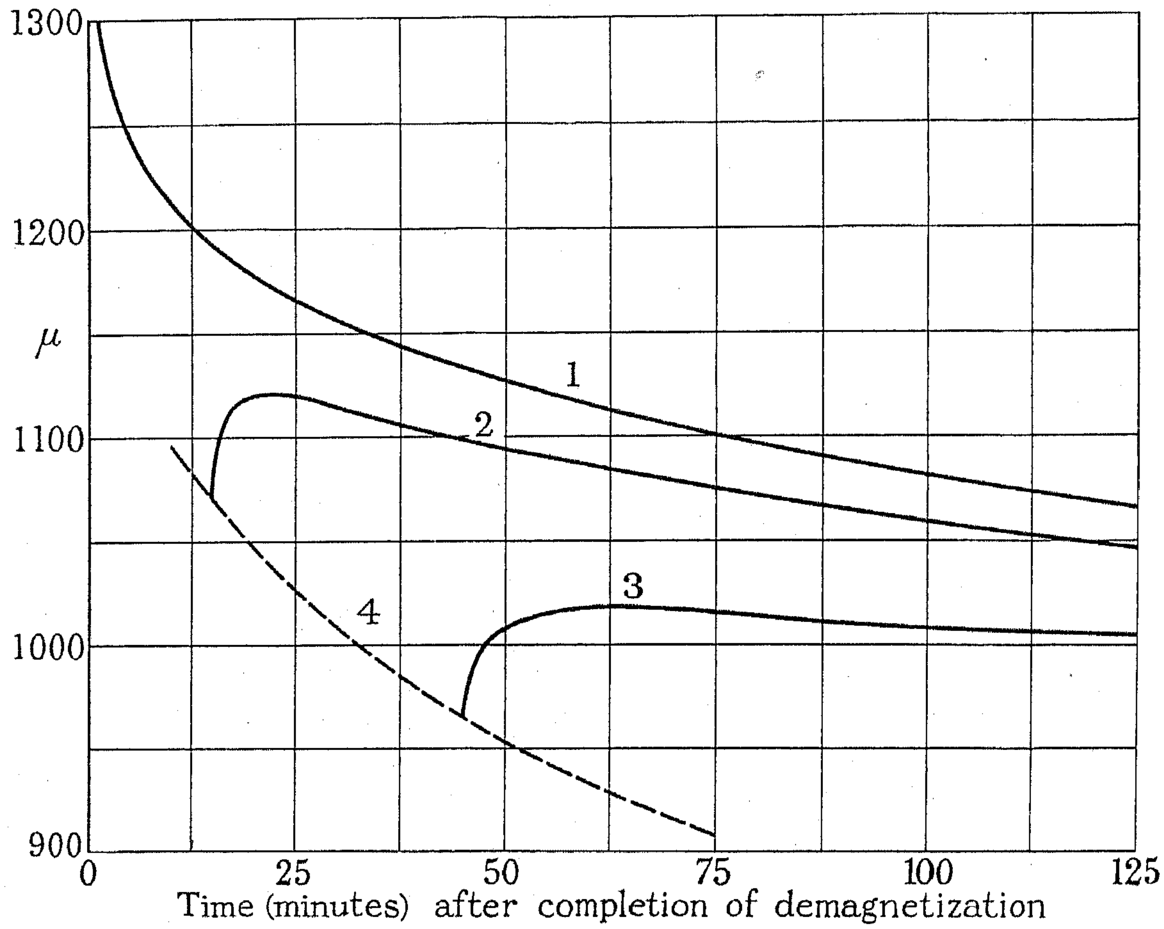

FIG. 2.—Variation of permeability with time, for high-silicon sheet material No. 17, at 50 cycles per sec. and $H_{max.} = 0 \cdot 01$.

(1) Alternating current switched on immediately after demagnetization.
(2) Alternating current switched on 15 minutes after demagnetization.
(3) Alternating current switched on 45 minutes after demagnetization.
(4) Alternating current switched off between readings.
Final value of $\mu = 540$.

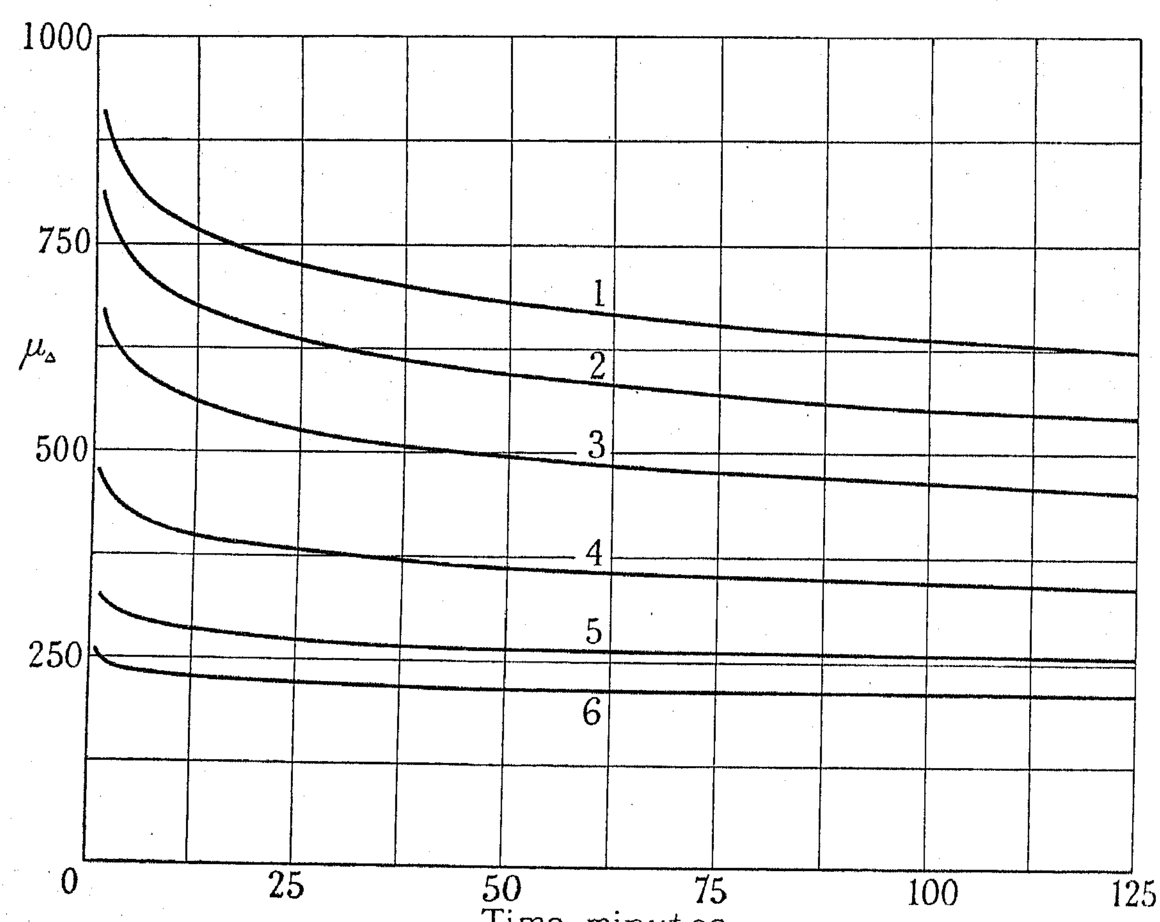

FIG. 3.—Variation of incremental permeability with time, for high-silicon sheet material No. 18, at 50 cycles per sec. and $H_{max.} = 0 \cdot 015$.

(1) $H_{D.C.} = 0$. (2) $H_{D.C.} = 0 \cdot 25$. (3) $H_{D.C.} = 0 \cdot 5$. (4) $H_{D.C.} = 1 \cdot 0$. (5) $H_{D.C.} = 1 \cdot 75$. (6) $H_{D.C.} = 2 \cdot 5$.

negligible until the range of H corresponding to the maximum permeability was reached.

The wide differences between the magnitudes of the time-decrease in different materials is shown by the results in Table 2. It is clear that the time-decrease is much greater in high-silicon specimens, whether laminated or solid, than in any other grade of material tested, the maximum value of D for these specimens being of the order of 100 per cent.

It is of interest, in view of the resemblance in many respects between aluminium- and silicon-irons, that the aluminium alloy, although containing only about 2 per cent of aluminium, displayed a considerably larger time-decrease than any other material except the high-silicon irons. Of the remaining materials only the low-silicon and other commercial iron sheets showed considerable time-decreases (5 to 18 per cent). In particular the time-decrease in the nickel-irons, especially mumetal, is extremely small. This is important in view of the extensive use of these materials in weak fields of the order of those at which the time-decrease attains its maximum value.

(3) *Time-decrease at Constant Flux Density.*

From the immediate and final permeability curves obtained experimentally, the corresponding curves connecting permeability and B were calculated and the time-decrease of permeability was deduced for various constant values of B. The maximum time-decrease for a given value of B, which was found to be considerably less than that for a given value of H, occurred at roughly the same value of B for all the materials tested, viz. $B = 8$ (approx.).

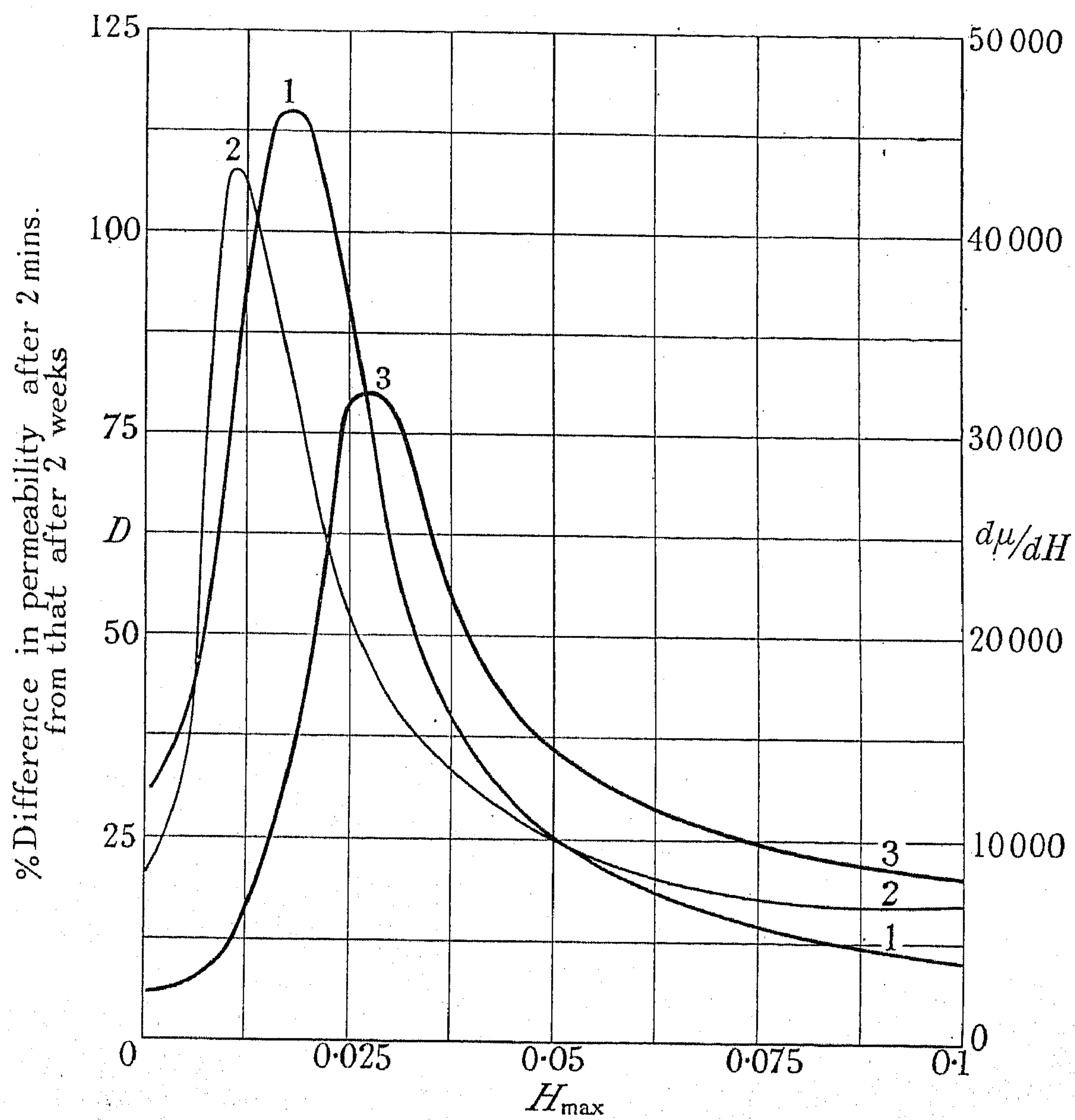

FIG. 4.—Curves showing difference in permeability and $d\mu/dH$, at 50 cycles per sec., for high-silicon sheet material No. 18, 2 minutes and 2 weeks after demagnetization.

(1) Percentage difference in permeability.
(2) $d\mu/dH$ 2 minutes after demagnetization.
(3) $d\mu/dH$ 2 weeks after demagnetization.

When the immediate and final permeability curves were being determined by the a.c. bridge method, the losses in these two conditions of the material were deduced from the current and the resistance reading. The accuracy of the loss measurements was not very great owing to the smallness of the resistance component compared with the inductance component, but above $B = 5$ an accuracy better than 2 per cent was obtainable in the loss measurement and this sufficed to show that the losses at a given flux density were slightly higher in the immediate than in the final condition. The maximum decrease, even in a high-silicon material, was

TABLE 2.

Time-decrease of Permeability in Various Specimens.

Specimen		At $H = 0 \cdot 001$		Maximum time-decrease		
No.	Material	μ_F	$D = \frac{\mu_I - \mu_F}{\mu_F} \times 100$	H	μ_F	$D = \frac{\mu_I - \mu_F}{\mu_F} \times 100$
1	Low-carbon steel	245	< 1	—	—	< 1
2	Armco iron	150	< 1	—	—	< 1
3	Transformer iron sheet ..	320	3	0·02	350	4
4	Electrical iron sheet	234	8	0·04	302	12·5
5	Lohys sheet	277	4	0·05	347	8
6	Special Lohys sheet	210	4·3	0·05	273	8
7	Low-silicon sheet	237	6	0·03	284	8·5
8		201	6·5	0·02	292	18
9		216	2·5	0·06	332	5·5
10	Nickel-iron sheet	2 045	1·3	0·013	2 120	2
11	Swedish iron	161	2·5	0·03	183	3
12	High-silicon sheet	249	30	0·025	327	78
13		351	23	0·02	435	48
14		329	35	0·018	428	135
15		327	32	0·018	409	76
16		286	31	0·038	400	103
17		405	54	0·009	516	142
18		346	32	0·018	450	115
19	High-silicon iron (solid) ..	442	43	0·018	513	90
20	Aluminium iron (solid) ..	120	10	0·06	163	36
21	Mumetal spiral	13 500	< 1	—	—	< 1

only about 5 per cent and diminished as B increased, disappearing above $B = 50$, although the decrease in permeability was still considerable.

(4) *Effect of Magnetizing Forces used in Measurements on Time-decrease.*

It was observed that, except at very small alternating magnetizing forces (not greater than about $H_{max.} = 0 \cdot 002$ in the high-silicon materials), the rate of time-decrease was less if the a.c. magnetizing current was left flowing continuously than if it was switched on for a few seconds only when each reading was being taken. This is illustrated by the results given in Table 3.

Also, if the specimen was left without any applied magnetization for some time after demagnetization and a small alternating magnetizing current was then switched on, the permeability increased for several minutes and then began to decrease slowly as shown in Fig. 2 (curves 2 and 3). If the material was left until the final value of permeability had been practically reached, the rate of increase was much smaller and after a period of some hours the permeability had still not attained its maximum value.

The reversals of magnetization employed in the ballistic method of testing also produced appreciable increases in permeability, except at very small magnetizing forces, when the specimen had been left for some time after demagnetization. In d.c. measurements, however, as has been pointed out in detail by Atorf,* it is very difficult to distinguish between the effects of time-decrease, accommodation by repeated cycling, and magnetic after-effect, all of which occur principally at low magnetizing forces.

TABLE 3.

Time-decrease with and without Alternating Magnetizing Current on between Readings.

High-silicon sheet material No. 12, a.c. magnetization of 50 cycles per sec., $H_{max.} = 0 \cdot 025$.

Time after demagnetization	Permeability	
	Current on	Current off
minutes		
15	540	492
60	504	431
120	483	413
250	456	386

It was also noticed that when the d.c. magnetization was kept on continuously (without reversal) the decrease of permeability was less rapid than when it was switched off between readings.

* See Reference (8).

(5) *Treatment Producing or Influencing Time-decrease.*

A number of tests were made to determine the precise conditions under which the initial increase in permeability was produced and the factors which affected the magnitude of the time-decrease. The following observations were made.

(*a*) As the maximum magnetizing force used in demagnetization was increased up to approximately the value corresponding to the maximum permeability, the immediate permeability increased; beyond this point no further increase occurred.

(*b*) The immediate permeability at a magnetizing force H_1 was unaffected by the rate of demagnetization down to about H_1, but diminished if the time taken to demagnetize from H_1 to zero was appreciable. This indicated that the time-decrease at H_1 began as soon as the amplitude of reversals fell to about H_1, though in view of the effect of reversals of the magnetizing current on the rate of time-decrease it probably did not attain its full normal rate until demagnetization was complete.

(*c*) The apparent permeability of a specimen, to which a magnetizing force of $H = 100$ had been applied and removed without subsequent demagnetization, decreased with time similarly and to approximately the same percentage amount as the normal permeability at the same magnetizing force after demagnetization. The initial increase in permeability is therefore due to a disturbance of the material by the application of a large magnetizing force, the time-decrease indicating a gradual return to its original equilibrium condition.

(*d*) The time-decrease was independent of the presence or absence of the earth's field and was, indeed, not appreciably affected by the presence of a uniform field as great as $H = 5$. Comparatively small changes in either direction in such a uniform field, however, produced a temporary increase in permeability in the same way as other magnetic disturbances.

(*e*) The application of a uniform alternating field of 50 cycles per sec. and $H_{max.} = 0 \cdot 25$ to the whole space containing the ring specimen scarcely affected the immediate permeability resulting from a given disturbance, but considerably reduced the rate of the subsequent time-decrease as if retarding the return of the material to its equilibrium condition.

(*f*) The materials which were susceptible to magnetic disturbance were also very susceptible to mechanical disturbances. Slight mechanical shocks or vibration such as were produced by moving the specimen, or even by moving other objects resting on the same table, caused increases in permeability amounting sometimes to several per cent. Violent shaking produced increases of the same order as the maximum effects of magnetic disturbance. These increases in permeability were followed by time-decreases exactly resembling those caused by magnetic disturbances, and therefore presumably of precisely similar nature.

(*g*) With increasing temperature the permeability increased slightly immediately after the application of a given magnetic or mechanical disturbance, but the subsequent time-decrease was enormously reduced. At 60° C. the decrease was only one-quarter as great as at room temperature, and at 100° or 150° C. the decrease was barely detectable after 2 hours (about 1 per cent). High temperature thus acts in a similar way to an alternating field or other disturbing factor in preventing the settling-down of the material into its normal equilibrium condition.

(6) *Shape of Permeability Curves and Time-decrease.*

The curve connecting permeability and magnetizing force, H, at low values of H for most of the materials tested could be represented fairly accurately by Rayleigh's formula, $\mu = a + bH$, where a and b are constants, but for certain specimens—particularly the high-silicon materials—the curve was of a more complicated shape. Typical μ/H curves of each kind are shown in Fig. 5. It will be seen that in the high-silicon material the permeability increases very rapidly with H over a narrow range of values of H in the neighbourhood of $H = 0 \cdot 02$. At higher values the rate of increase of permeability diminishes up to about $H = 0 \cdot 1$ and then again increases as the region of maximum permeability is approached.

TABLE 4.

Values of H for which dμ/dH and D′ attain their Maxima.

High-silicon sheet material No. 18, a.c. magnetization of 50 cycles per sec.

Time after demagnetization	Value of H for maximum $d\mu/dH$		Value of H for maximum D'
	Individual curves	Mean	
0 (calculated curve)	$0 \cdot 008$		
		$0 \cdot 009_5$	$0 \cdot 009_5$
2 minutes ..	$0 \cdot 011$		
		$0 \cdot 012$	$0 \cdot 011_5$
15 minutes ..	$0 \cdot 013$		
		$0 \cdot 013_5$	$0 \cdot 013$
2 hours	$0 \cdot 014$		
		$0 \cdot 016$	$0 \cdot 016$
10 hours	$0 \cdot 018$		
		$0 \cdot 022_5$	$0 \cdot 022$
2 weeks	$0 \cdot 027$		

The property of the μ/H curves for high-silicon materials of displaying a double flexure at low values of H has been previously noted by Yensen,* who also pointed out its practical importance in the deducing of threshold permeability. The characteristics of the curves for high-silicon material are shown even more clearly by the derived curves connecting $d\mu/dH$ and H given in Fig. 4, curves 2 and 3; the corresponding curves for the Lohys specimen being given in Fig. 6, curves 2 and 3.

To distinguish the first maximum of $d\mu/dH$ from that occurring as the region of maximum permeability is approached, they will be referred to as the α— maximum and β— maximum respectively. In the high-silicon specimens the α— maximum was often higher than the β— maximum, but in the other materials it was much

* See Reference (11).

less pronounced and sometimes scarcely detectable. Thus the specimens displaying large time-decreases of permeability are also those with a marked $\alpha-$ maximum.

curves 2 and 3) reveals a marked similarity in their general shape, while the maximum value of D occurs at a value of H which is approximately the mean of the

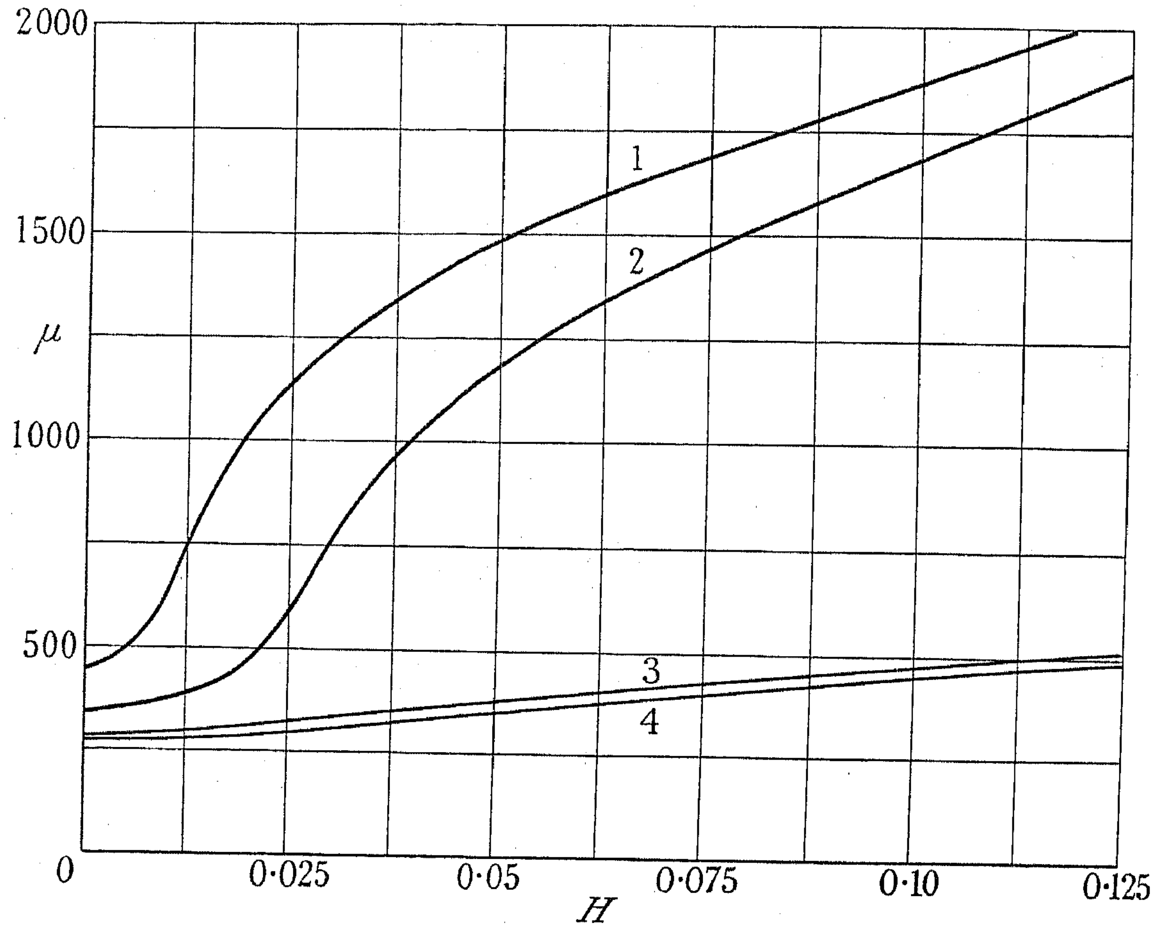

FIG. 5.—Permeability curves, at 50 cycles per sec., 2 minutes and 2 weeks after demagnetization.

(1) High-silicon sheet No. 18; 2 minutes.
(2) High-silicon sheet No. 18; 2 weeks.
(3) Sheet iron (lohys) No. 5; 2 minutes.
(4) Sheet iron (lohys) No. 5; 2 weeks.

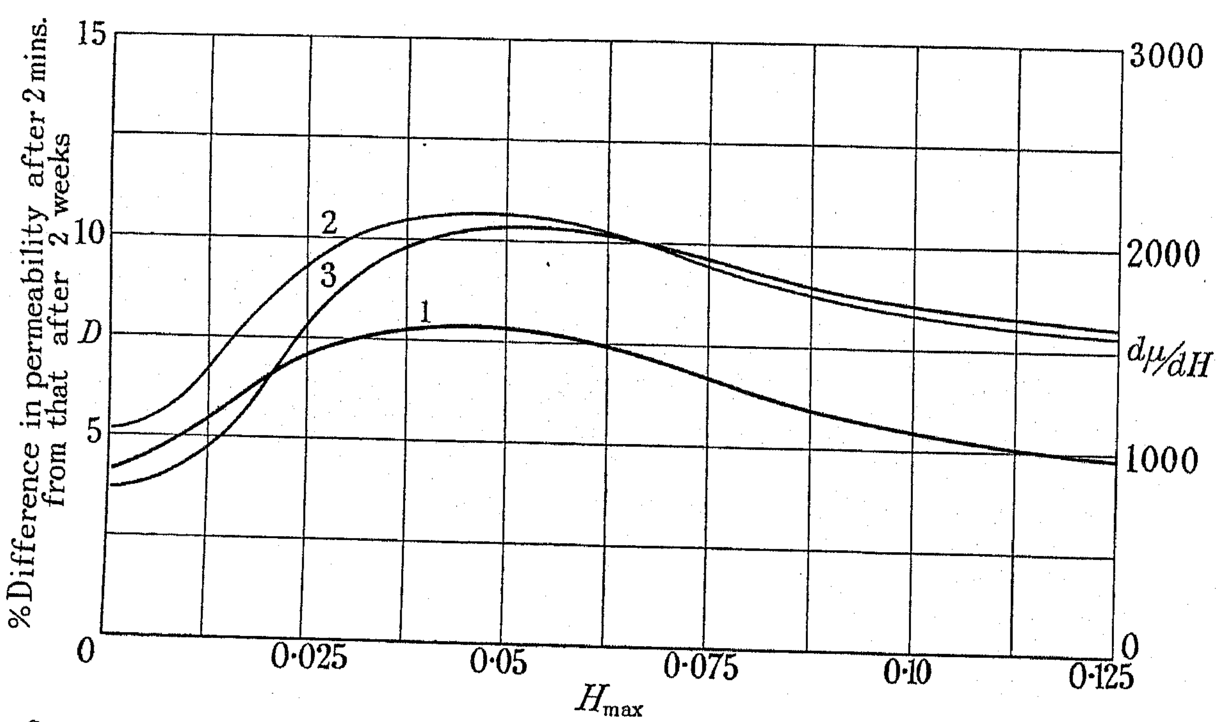

FIG. 6.—Curves showing difference in permeability and $d\mu/dH$, at 50 cycles per sec., for sheet iron No. 5, 2 minutes and 2 weeks after demagnetization.

(1) Percentage difference in permeability.
(2) $d\mu/dH$, 2 minutes after demagnetization.
(3) $d\mu/dH$, 2 weeks after demagnetization.

Moreover, a comparison of the curves of variation of time-decrease, D, with H (Figs. 4 and 6, curve 1) with the curves connecting $d\mu/dH$ with H (Figs. 4 and 6, values giving the $\alpha-$ maxima of the immediate and final curves of $d\mu/dH$.

Owing to the variation with time of the value of H

TABLE 5.

Correlation of Maximum Time-decrease with Functions derived from Permeability Curve.

Specimen No.	Specimen Material	(1) Maximum D	(2) $d\mu/dH$	(3) dB/dH	(4) $Hd\mu/dH$	(5) Values of ratios (2)/(1)	(6) (3)/(1)	(7) (4)/(1)
			(at H for maximum $d\mu/dH$ of curve after 2 minutes)					
4	Electrical iron ..	12·5	3 100	488	140	250	39	11
5		8	2 150	460	95	270	58	12
6		8	2 100	400	105	260	50	13
7	Low-silicon sheet ..	8·5	2 900	396	85	340	47	10
8		18	10 500	550	205	580	31	11·5
12	High-silicon sheet ..	78	14 000	780	280	180	10	3·6
13		48	13 000	710	160	270	15	3·3
14		135	51 000	1 340	610	380	10	4·5
15		76	21 000	890	275	280	11·5	3·6
16		103	19 000	1 090	460	180	10·5	4·5
17		142	95 000	1 375	475	670	9·5	3·4
18		115	43 000	1 250	475	370	11	4·1
19	High-silicon iron ..	90	28 000	1 110	310	310	12·5	3·4

at which the $\alpha-$ maximum occurred, it was necessary, in order to make a more precise comparison with the value of H for the maximum time-decrease, to deal with the changes in more limited periods. Permeability curves 15 minutes, 2 hours, and 10 hours, after demagnetization were therefore obtained for the high-silicon specimen in addition to those at 2 minutes and 2 weeks after demagnetization, already determined. The curve corresponding to zero time was also deduced from these observations by the method described below. In Table 4 the value of H at which the $\alpha-$ maximum occurred is given for each of these curves, and the mean of these values for each pair of successive curves is compared with the value of H at which the maximum time-decrease D' occurred between that pair of curves. The two maxima are found to be practically coincident in every case.

Attempts were made to find a derivative function of the permeability curve which would give a quantitative indication of the time-decrease to be expected. Table 5 gives for a number of specimens the maximum time-decrease, the values of $d\mu/dH$, dB/dH, and $Hd\mu/dH$ at the $\alpha-$ maximum point on the immediate curve, and also the ratio of each of these quantities to the maximum time-decrease, but although a fair degree of constancy in these ratios is obtained within each of the two groups of specimens (i.e. high-silicon materials and other materials), especially in the ratio $\dfrac{Hd\mu/dH}{D}$, the fact that the ratio differs substantially for the two groups seriously reduces the value of any of these functions as a criterion of the liability of the materials to time-decrease.

MATHEMATICAL EXPRESSION FOR TIME-DECREASE.

The form of the curves of time-decrease suggested an exponential expression for the percentage excess of the permeability at time t above the final undisturbed value μ_F, but no formula involving only two arbitrary constants appeared satisfactory. The experimental results could be fitted within the limits of experimental error, however, by an expression of the form $\delta = K\epsilon^{-At^n}$, where $\delta = 100(\mu - \mu_F)/\mu_F$ = percentage excess of permeability at time t above the final value, and K, A,

TABLE 6.

Comparison of Experimental and Calculated Values of Time-decrease.

(1) High-silicon sheet material No. 12, a.c. test; $H_{max.} = 0{\cdot}025$; formula, $\delta = 102\epsilon^{-0{\cdot}23t^{0{\cdot}25}}$.

(2) High-silicon sheet material No. 14, a.c. test; $H_{max.} = 0{\cdot}02$; formula, $\delta = 191\epsilon^{-0{\cdot}27t^{0{\cdot}25}}$.

(3) High-silicon iron (solid) No. 19, d.c. test; $H = 0{\cdot}02$; formula, $\delta = 122\epsilon^{-0{\cdot}2t^{0{\cdot}25}}$.

Time after demagnetization	Values of δ (1) Experimental	(1) Calculated	(2) Experimental	(2) Calculated	(3) Experimental	(3) Calculated
min.						
2	77·6	77·7	137·8	138·5	96·2	96·2
5	72·7	72·8	126·7	127·6	90·6	90·4
20	62·4	62·7	108·0	108·0	81·0	80·0
50	55·2	55·3	93·7	93·1	71·7	71·7
200	41·9	42·9	68·7	69·2	—	—

and n are constants depending on the material and conditions of test. After this formula had been derived empirically it was found that the same expression had been given by Wild and Perrier* as applicable to both time-decrease and ordinary ageing.

* See Reference (4).

As in all formulæ of this type, an alteration could be made in one constant involving considerable changes in the other two constants without causing serious departure from the experimental results. Thus, although the results on the high-silicon specimens showed considerable non-systematic variations in the value of n when the constants were first evaluated, it was found that if n was taken as $0 \cdot 25$ satisfactory agreement with the observed permeabilities could be obtained at all values of H (see Table 6).

TABLE 7.

Variation with H of Constants in Formula for Time-decrease.

High-silicon sheet material No. 18, a.c. test; value of n in formula, $\delta = K\epsilon^{-At^n}$, taken as $0 \cdot 25$.

H	K	A
0·00325	71·5	0·58
0·0067	96·5	0·52
0·0105	144	0·54
0·0134	174	0·42
0·01675	163	0·29
0·02095	145	0·225
0·02515	125	0·19
0·0293	83	0·19
0·0400	45	0·19

The constant K in the formula is of considerable interest since it expresses the value of δ when $t = 0$, and hence the highest permeability obtainable by disturbing the material at the particular magnetizing force in question is given by $(1 + \frac{1}{100}K)\mu_p$. Typical results of the determination of the constants for a high-silicon material are given in Table 7, which shows that K rises to a maximum of 170 at $H = 0 \cdot 013$ and then diminishes rapidly with further increase of H. In this specimen, therefore, the permeability immediately after disturbance may rise to nearly three times its final equilibrium value.

TABLE 8.

Variation with Polarizing Magnetization of Constants in Formula for Time-decrease.

High-silicon sheet material No. 18; a.c. magnetization of 50 cycles per sec.; $H_{max.} = 0 \cdot 015$; value of n in formula, $\delta = K\epsilon^{-At^n}$, taken as $0 \cdot 25$.

$H_{D.C.}$	$B_{D.C.}$	K	A
0	0	170	0·35
0·25	900	173	0·39
0·5	2 800	148	0·44
1·0	5 500	104	0·53
1·75	7 600	75	0·54
2·5	9 000	47	0·68

The influence of a polarizing d.c. magnetization on the constants in the formula for the time-decrease of incremental permeability is illustrated by the results in Table 8, which have been derived from the curves shown in Fig. 3 and refer to the same specimen as Table 7. With increasing d.c. magnetization the value of K, after being at first practically constant or even rising slightly, diminished steadily while the value of A increased from $0 \cdot 35$ to $0 \cdot 7$ at $B = 9\,000$. This indicates that the polarizing magnetization diminishes the total time-decrease but increases relatively the rate at which the decrease takes place.

CONCLUSIONS.

It appears from the foregoing results that in many ferromagnetic materials the application of a magnetic or mechanical disturbance produces an increase in the permeability at small magnetizing forces, which, if the disturbance is not continued or repeated, gradually disappears with time until after a few days or weeks a final equilibrium condition is attained. An explanation of these effects in terms of the Weiss–Heisenberg theory of ferromagnetism has been given by Atorf,* and it is proposed here to refer only to the practical aspects of the phenomena.

The changes in permeability produced are much greater in high-silicon alloys than in any other material tested, and it is only in these alloys that they are sufficiently large to have much practical significance.

The effects observed in high-silicon iron specimens may be summarized as follows:—

(1) The permeability at a given low magnetizing force is increased by a disturbance to a value which may be nearly 200 per cent higher than that found when the specimen has been left for a long period undisturbed.

(2) After the application and removal of a disturbing force, magnetic or mechanical, the excess of the permeability over its final equilibrium value disappears gradually with time according to the formula $\delta = K\epsilon^{-At^n}$. Theoretically, therefore, the time-decrease should continue indefinitely, but in practice the effects of incidental mechanical shocks or vibration and of the magnetizing force used in the measurements limit the period during which a decrease is observed to about 2 weeks.

(3) The incremental permeability varies similarly to the normal permeability after a disturbance, but as the polarizing d.c. magnetization is increased the magnitude of the time-decrease diminishes and ultimately becomes negligible.

(4) At a temperature of about 100° C. the time-decrease of permeability after a disturbance becomes very small, and the permeability obtained is approximately that found at room temperature immediately after a disturbance. High temperature thus apparently acts as a disturbing factor. A uniform alternating field produces a similar effect.

These effects appear to be an inherent property of the material and to be related to the shape of the permeability curve, since the materials displaying them most strongly have a sharp maximum in the curve connecting $d\mu/dH$ with H at the value of H at which the largest time-decrease occurs. This characteristic of

* See Reference (8)

the permeability curve presumably indicates that the configuration of the magnetic elements in fields of this order is relatively unstable, and it is therefore not surprising that the maximum tendency for the permeability to vary spontaneously after a disturbance occurs at this value of H. The reason why the presence of a comparatively small percentage of silicon, or to a less extent of aluminium, produces such a large increase in the instability in weak fields is not known but doubtless depends on some peculiarity in the structure of the crystal lattice.

The relation of the time-decrease of permeability to ageing is of interest. Wild and Perrier* regarded the two effects as identical because they could be represented by the same formula, the constants in which had the same values and varied similarly with temperature for both processes. As already pointed out, this view is inconsistent with the generally accepted theories of the nature of ageing. Moreover, the high-silicon alloys, which age very little, display exceptionally large time-decreases. It seems probable, therefore, that the two effects are distinct in origin but that the rate at which each change takes place is controlled by the same factors, and hence the constants in the expressions representing the two changes are closely related.

The flux densities at which the time-decrease of permeability is appreciable are so low that the effect on the normal permeability of materials is rarely likely to have any practical importance. Where superposed d.c. and a.c. magnetizations are being used, however, it is quite common for an alternating flux density of the order of magnitude for which the time-decrease attains its maximum value to be superposed on a constant flux density. In these circumstances, therefore, a decrease with time in the inductance to the alternating current of iron-cored coils would be expected after switching on or otherwise varying the d.c. magnetization. Such decreases have been observed, but are not usually very large, partly, no doubt, owing to the effect of the reluctance of the joints and partly owing to the influence of the polarizing magnetization in reducing the time-decrease.

The effects of the time-decrease are likely to be of greater practical significance in the testing of materials at low flux densities. Values of permeability and incremental permeability obtained at flux densities below $B = 1\,000$ on certain materials will depend appreciably, and in the neighbourhood of $B = 8$ enormously, on the time after demagnetization or after switching on the polarizing magnetization at which the tests are made. It is noteworthy that the American Society for Testing Materials† specifies for tests of permeability and core loss at low inductions a flux density of $B = 10$, the material being thoroughly demagnetized before testing. This standard flux density coincides almost exactly with the maximum of the curve connecting time-decrease with B. While the time-effect on power losses is very small, it is desirable, if consistent results are to be obtained in permeability measurements (normal or incremental) at low flux densities, to standardize the time after demagnetization or d.c. reversal at which the tests are to be made. In normal permeability measurements the problem is not a serious one, because, apart from the range of magnetization for which time-effects are large being seldom important, the specimen can be demagnetized once for all, left for a period of several hours (e.g. overnight), and the readings then obtained consecutively with ascending values of H. In incremental permeability measurements, on the other hand, the effects of time-decrease are much more troublesome because of the low flux densities at which these tests are usually made and also because an adjustment of a comparatively large polarizing flux density has to be made before each reading, which disturbs the material and initiates a large time-decrease. A procedure that has been used for laboratory measurements is to take each reading after a period of 20 minutes has elapsed from the final reversal of the d.c. magnetization; by this means good consistency in the repetition of results is secured, while the values obtained fall about midway between the immediate and final permeabilities. An interval of 20 minutes before each reading would probably be unduly long in commercial testing, and it is not desired to suggest that it should be generally adopted. It is urged, however, that some definite practice in this matter should be standardized; since it must be realized that, in the absence of a statement of the time-interval elapsed after demagnetization or other disturbance, permeability values, whether normal or incremental, at flux densities below about $B = 1\,000$ cannot be regarded as having a precise significance.

* See Reference (4).

† *Ibid.*, (12).

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AUTOMOBILE ELECTRICAL EQUIPMENT.*

By K. R. Sturley, Ph.D., B.Sc., Graduate.

(Abstract *of Paper read before the* London Students' Section *9th December*, 1932.)

Introduction.

Though the general principles involved in the electrical equipment of the motor-car may be well understood the details are usually little known. The object of this paper is, therefore, to give a description of the electrical devices for ignition, lighting, starting, and accessories, and to explain, where necessary, their functions.

(1) Ignition.

Coil Ignition Systems.

A coil ignition system includes a combined distributor and contact breaker, the latter being connected to the primary of the coil and the former to the secondary. In some cases the coil and distributor are mounted in one unit which is interchangeable with a magneto, but this is not usual practice.

The coil.—The coil has a laminated iron core upon which is wound a secondary of about 15 000 turns of fine wire. Dissipation of heat is facilitated by placing the primary winding outside the secondary. The ignition

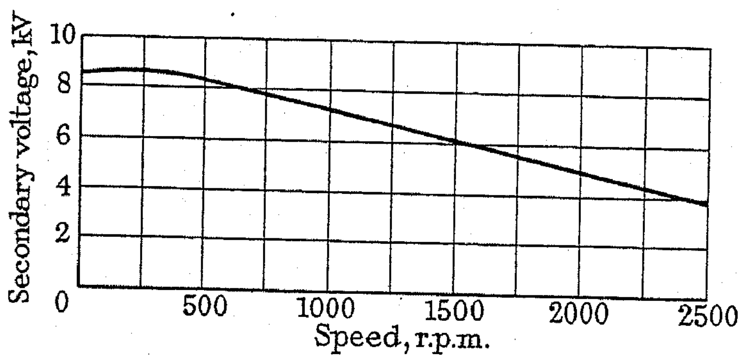

Fig. 1.—Secondary-voltage/speed curves for coil ignition set.

switch is interposed between the positive battery terminal and the joint end of the primary and secondary coils. The other ends of the coils are connected to the distributor and contact breaker.

The secondary voltage reaches a maximum about 0·2 millisecond after the rupture of the primary current, and the curve in Fig. 1 shows the effect of the speed of interruption upon the voltage. The reduction in secondary voltage with increase of speed is mainly due to increased iron and resistive losses.

Contact breaker and distributor.—The tungsten contact-breaker points are stationary and located beneath the distributor arm. They are actuated by a hardened-steel cam which carries the distributor arm. One contact point is connected to earth, or the negative terminal of the battery, and the other is carried on a lever arm to which is riveted a fibre heel. This heel is maintained in contact with the cam by a spring, which also serves as an electrical connection to the primary of the coil. A condenser of 0·2 μF parallels the points. The high-tension lead from the secondary is led to the centre of the distributor moulding and is connected to the

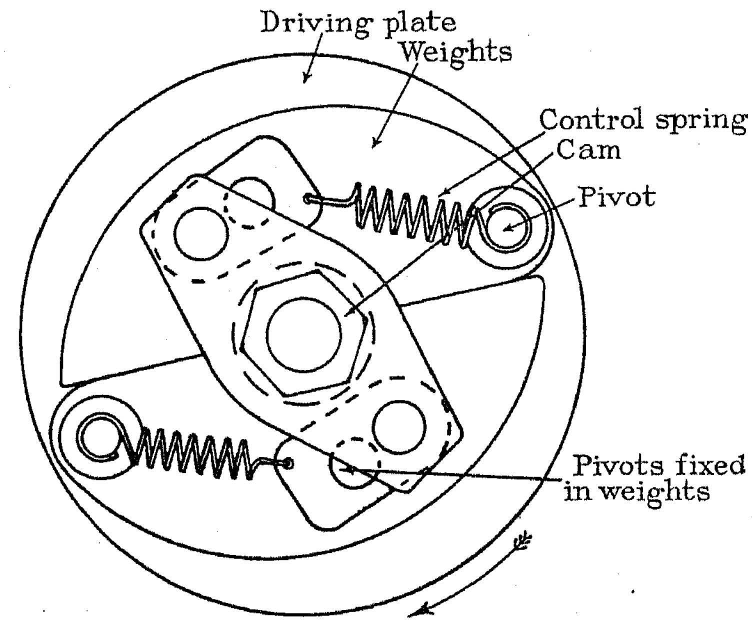

Fig. 2.—Centrifugal ignition-advance mechanism.

rotating arm by a carbon brush. The moulding has nickel inserts connected to their respective sparking plugs. The distributor arm may be fitted with a carbon brush, but it is more usual to employ a nickel tip with a slight clearance between it and the inserts in the moulding.

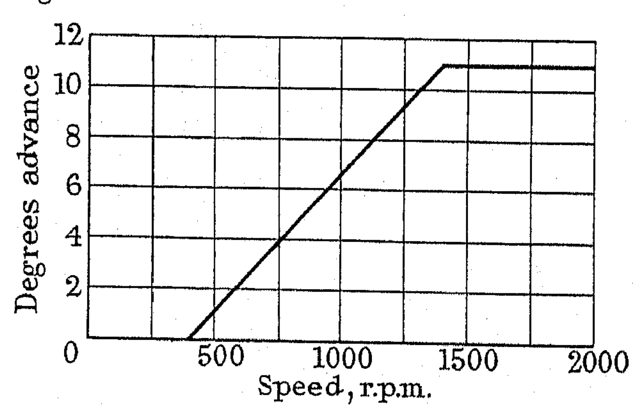

Fig. 3.—Automatic ignition-advance curves for centrifugal governor.

All distributors for 8- or 12-cylinder engines are fitted with double lever arms carrying contact breakers connected in series. In the case of an 8-cylinder engine a 4-lobe cam is used and each breaker opens four times per revolution, giving a total of eight breaks. An 8-lobe cam would not be satisfactory except at low speeds, owing to the inertia of the contact lever.

* A Students' Premium was awarded by the Council for this paper, and it is the practice of the Council in such cases to publish the paper, in full or in abstract, in the *Journal*.

Automatic control of ignition.—Coil ignition systems are often fitted with some form of automatic timing control, which may be operated by weights and/or by suction from the induction manifold of the engine. Centrifugal control does not function below a speed of 400 r.p.m., and for complete control a combination of the two systems is necessary. Figs. 2 and 3 show the construction of the centrifugally-operated mechanism and its effect on the timing respectively. The arrangement of the suction-operated device is indicated in Fig. 4. When the engine is taking a heavy load the suction falls and the control spring returns the diaphragm to the retard position.

Magneto Ignition Systems.

The magneto differs from the coil ignition system in that it generates its own primary current, using a permanent-magnet field system which may be either fixed or rotating. The first class is known as the rotating-armature and the second as the polar-inductor type. Each has two windings, a primary of few turns and low resistance and a secondary of a large number of turns. One end of the primary coil is connected to

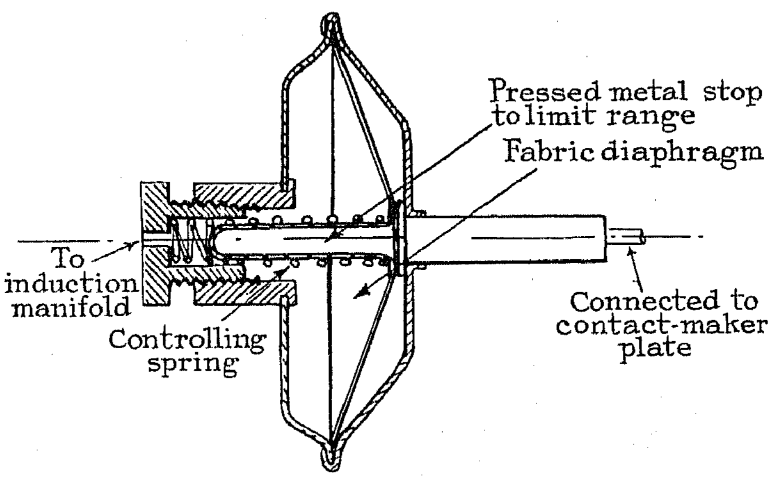

FIG. 4.—Suction automatic ignition-advance control.

earth and the other to the secondary. The contact breaker parallels the primary, and the current in the latter is broken just before the point where a reversal of flux through the armature is about to take place. One disadvantage of the magneto is that control of timing affects its efficiency of operation by breaking the primary current after the maximum has been reached. This has been obviated by using movable pole-tips connected to the cam ring so that a break occurs at the same relative position of the magnetic field when the timing is retarded.

Automatic timing control.—The polar-inductor magneto is sometimes fitted with a centrifugal timing control placed between the drive and the rotating poles.

(2) LIGHTING AND CHARGING EQUIPMENT.

The charging unit has to be compensated to limit its output over a wide range of speed; this may be achieved in two ways, by the constant-current or by the constant-voltage dynamo.

Constant-Current Dynamo.

Fig. 5 gives the diagram of connections; it will be noticed that the negative end of the field coil is connected to an auxiliary brush. Armature reaction prevents excessive output currents, and the maximum output of the dynamo can be increased or decreased by moving the auxiliary brush towards or away from the negative brush.

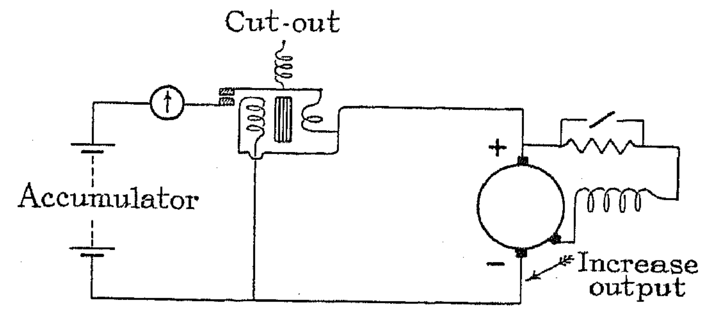

FIG. 5.—Connections for constant-current dynamo.

Constant-Voltage Dynamo.

This consists of a shunt-wound machine fitted with a vibrating regulator, the connections for which are shown in Fig. 6. The current or series winding in the field circuit of the regulator safeguards the dynamo from excessive charging currents when the battery is in a badly discharged condition.

Cut-out.

To prevent the battery discharging through the dynamo at low engine speeds, a cut-out is placed in the dynamo positive lead.

Dipping Reflectors.

Electrically-operated dipping reflectors generally consist of a solenoid with two coils, one of low and the other of high resistance. The first applies the initial large force and is automatically cut out when the reflector is in the dipped position, where it is held by the current in the high-resistance coil. In certain cases twin-filament bulbs are used and the effect of dipping is obtained by switching over from the normal filament to a second one partially hooded by a metal cap.

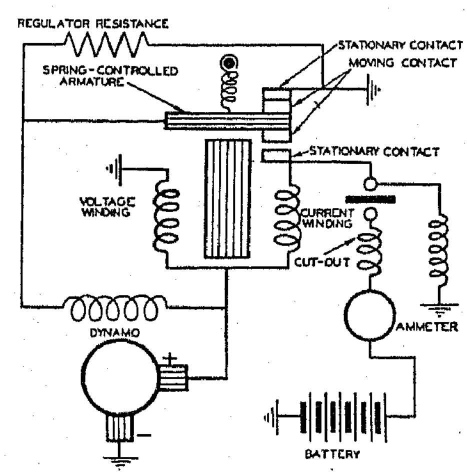

FIG. 6.—Regulator for constant-voltage dynamo.

(3) STARTING.

An important feature of the equipment of automobiles is the self-starting device operated from the battery. The design of suitable motors presents difficulties owing to the low voltage available. It is essential that the resistance of the motor should be low, and it is usually

not higher than 0·025 ohm for a 12-volt machine. To reduce resistance losses to a minimum the starting switch is often placed on the starter motor and the contacts operated by a solenoid.

Types of Starter Drives.

The two methods now in use are the Bendix and the axial systems, the latter being almost entirely confined to commercial vehicles.

Bendix coupling.—A screwed sleeving, on an extension of the armature shaft and connected to it by a coil spring, carries the starter pinion. The inertia of the pinion causes it to wind up the sleeving sufficiently to engage with the flywheel when the armature is rotated at speed. A shoulder on the sleeving limits the travel of the pinion, and the coil spring then applies the full torque to the engine. When the engine picks up, the pinion is automatically thrown out of engagement.

Axial starter.—In the axial drive, so named because the armature is capable of axial movement on its bearings, a spring holds the armature out of the magnetic field. The motor has an auxiliary field winding besides the main series field, and closing of the starter switch brings only the first into action. The slowly-rotating armature is pulled into the magnetic field, thus bringing the pinion into mesh with the flywheel. When almost at the end of axial travel the armature operates a switch introducing the main series field for the motor to exert its full torque. When the engine fires, the current taken by the motor is insufficient to overcome the tension of the spring and the armature is automatically disengaged. A clutch having a slipping torque below that necessary to shear the pinion teeth is fitted between the pinion and the armature.

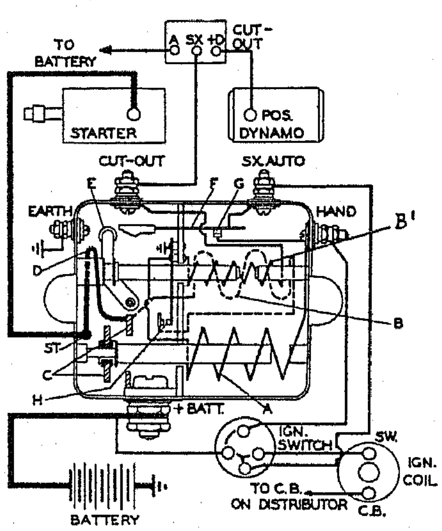

FIG. 7.—Schematic diagram for automatic starting.

Automatic Starting.

The employment of starting devices operated from the ignition switch appears to be increasing, and the mechanism for achieving this function has several points of interest. A schematic diagram of connections is given in Fig. 7. The apparatus consists of two solenoid-operated switches. The first, represented by A, is connected to the ignition switch and to earth through the contacts at G. The second solenoid is actuated by three coils; one (B) in parallel with the starter, one (B′) across the dynamo terminals, and one (D) a single-turn coil in series with the starter and producing a magnetic field in opposition to B and B′. The ignition switch actuates the plunger in coil A, thus closing the main starter contacts at C, but coil B is not immediately energized because a flange on the plunger imparts a vibration to the arm carrying the contacts H in series with the coil. This delay period allows the pinion to engage with the flywheel for the starter to take full load, when the current in coil D maintains the trip plunger in the "out" position. As soon as the engine fires this current is reduced, the voltage across B rises, and the dynamo begins to energize B′ so that the plunger is attracted. In its travel it pulls up lever E, which opens the contacts at G and releases the first plunger. Coil B′ retains the second plunger in position so long as the engine is running, but should it stall the plunger is released and after a delay of about 1 second the cycle of starting operations is repeated. This delay, allowing the engine to come completely to rest, is achieved by vibration of the spring arm F carrying the contacts G on the release of the trip plunger. Coil A is not energized until the vibration has ceased.

(4) ACCESSORIES.

Motor-operated Horn.

About 40 watts is required to operate the series-wound motor satisfactorily. A toothed wheel on the end of the armature shaft strikes a button on the diaphragm, and the intensity of the sound is affected by the pressure between button and ratchet.

High-frequency Horn.

Vibration of the diaphragm is produced by interrupted electromagnetic action controlled by the diaphragm itself, at the centre of which operates the electromagnet whose coil is connected to make-and-break contacts. When the electromagnet is energized, a peg connected to the diaphragm strikes the end of a lever arm carrying the contacts.

Electric Windscreen Wipers.

Non-self-starting type.—The armature consists of a laminated unwound iron rotor which has four lobes. The 2-pole stator has a field coil connected in series with contacts operated by a 4-lobe cam on the rotor shaft. This type takes about 8 watts for normal operation.

Self-starting type.—The motors of these screen-wipers have a 2-pole shunt field and a 3-pole armature. The former takes about 6 watts, and a total of 15 watts is required on full load. The normal armature speed is 1 500 r.p.m., and the gear-reduction ratio gives a speed of 30 wipes per minute on the screen, a wipe being considered to be a forward and reverse stroke.

CONCLUSION.

The scope of the paper has had necessarily to be limited to the more essential apparatus.

The author desires to acknowledge his indebtedness to Mr. J. L. White, of the Lucas Research Laboratories, for certain of the curves and information.

ELECTRICAL INTERFERENCE WITH BROADCASTING.

INTERIM REPORT OF THE COMMITTEE TO THE COUNCIL.*

The Committee, appointed by the Council in May, 1933, have held 7 meetings. They have received valuable help from their Technical Secretariat and the organizations represented by its members, viz. the G.P.O., the B.B.C., the E.R.A., and the I.E.E. Evidence and assistance from a number of official and unofficial bodies have been given to the Committee, as a result of which it was confirmed at an early stage that radio interference was widespread and constituted a serious annoyance to the public. The knowledge of the technical side of the question of radio interference has advanced considerably during the year under review, and the Committee have, they believe, been instrumental in no small measure in fostering a desire to rectify the trouble and to bring together in mutual effort those who are able to take action towards its elimination. The Committee are convinced of the importance of solving this difficulty quickly, and of securing the co-operation of the many sections of the industry, without whose goodwill and help little can be achieved.

The Committee find that listeners and those who advise them have not yet done on their receiving sets all that is possible to mitigate some of the effects of interference. A memorandum, prepared for the Committee by the B.B.C., on the features of design and installation of radio sets which, when attended to, help to lessen and sometimes greatly to lessen the trouble, is reproduced in Appendix I. The Committee consider that these precautions should receive the special attention of those who supply radio sets and their components and who give service of radio sets to the public. On the Continent of Europe (where State regulations for the suppression of certain phases of interference are favoured) there is a strong tendency to give but little assistance to the listener who is not prepared to take such reasonable precautions against interference as are within his power.

Nevertheless, even given such favourable conditions as the listener can provide, there is left a large amount of interference which can only be effectively corrected by suppression at the source—that is to say by fitting suitable condensers (and sometimes condensers with choke coils) to existing types of apparatus causing the interference, and by improvement in design of new models. Such interfering apparatus usually contains a commutator motor, but exceptions to this occur in large plant such as mercury rectifiers or high-tension lines which, under certain conditions, may cause trouble. Apparatus in which a contact or contacts are only occasionally operated need not be considered objectionable if properly maintained.

It appeared to the Committee early in their deliberations that preparations should be made by which manufacturers of interfering apparatus could know how to apply the necessary correction and how to appraise the interference. The Committee therefore took the initiative in the preparation of a specification covering this side of the subject, as a first step towards assisting those manufacturers who desired to produce interference-free appliances. It might be difficult, to commence with, to apply correction to much existing apparatus, but there seemed every reason to make the way as plain as possible for those who desired to render new apparatus inoffensive. In the preparation of the specification the Committee have had the co-operation of the British Standards Institution and it is expected that it will be possible to issue the Specification early next year, without extensive modification, as a British Standard.

The Committee accepted the duties of secretariat for the Special Committee of the International Electrotechnical Commission on Radio Interference which is concerned with International Standardization. The meeting, which was held in Paris at the end of June, 1934, was particularly opportune, as it provided an approximate idea of the level of interference which other countries are thinking of accepting as permissible in connection with their regulations. As far as can be seen, this permissible level is more tolerant than any of the countries would like to be in a position to prescribe, and more so than the Committee have desired to adopt as an "objective." But the Committee have agreed that if hard-and-fast regulations are to be laid down at the present time the more tolerant figure is inevitable. A record of the Paris meeting and its official conclusions is reproduced in Appendix II.

The Committee are reluctant to be dogmatic on the subject of compulsory versus voluntary suppression of radio interference. It is not the tradition in England to make regulations until it is certain firstly that they are needed, and secondly that they can be carried out effectively when made. There is at present much goodwill amongst all concerned, and readiness to help to rectify trouble where it is serious; the Committee believe that in many directions a threat now to impose compulsory regulations might have the effect of retarding rather than enhancing these influences. But when co-operation and goodwill have done their best there may be a residuum of recalcitrant cases in which some form of compulsion will probably be desirable. The manufacturers of household apparatus are unwilling at the moment to express themselves definitely on the question of compulsion. The extent of the increase in price of appliances appears to depend materially on the level of interference which is permissible. Manufacturers have been very ready to prepare technically the design of non-interfering apparatus, but on account of increased price there may be a reluctance to market such apparatus until the requirement is made to apply to all—including importers. This, however, is in the nature of surmise and is not at the moment a practical issue because the

* Also see vol. 73, pp. 93 and 543, vol. 74, p. 470, and vol. 75, p. 813.

Committee consider that more experience and investigation are needed before there can be any feeling of certainty that the proposed standards and methods of appraisement of radio interference are practical and could be effectively included in any form of official regulations. Although, as mentioned earlier, certain Continental countries are already imposing regulations for a measure of compulsory suppression at the source, the Committee would prefer to see the technical standards and methods to be used better established before considering whether or not this country should follow their example.

APPENDIX I.

The Effect of Different Broadcast Receiver Equipments on Interference Ratios: A Review of Possible Steps which can be Taken by the Listener to Ameliorate the Effects of Existing Interference.

Introduction.

When it is desired to reduce electrical interference to a broadcast receiver, there are three possible points at which an attempt can be made:—

(*a*) The receiver equipment itself, including its aerial and earth systems.
(*b*) On the mains, by means of:—
  (i) Smoothing circuits at the receiver.
  (ii) The insertion of a filter device at the point where the mains enter the listener's premises.
(*c*) At the source of the interference itself.

It is the object of these remarks to discuss all possible precautions which the listener might take to reduce the interference, as mentioned in (*a*) and (*b*) above.

(1) Aerial Systems.

In installing a broadcast receiver with its aerial and earth systems, steps should be taken to obtain the maximum pick-up of programmes and the minimum pick-up of interference. This ratio may in certain circumstances be influenced over quite wide ranges by the design and position of the receiving aerial. If, for example, a receiver is installed in a steel-frame building and a small indoor aerial (say, one run along a picture rail inside the room) is used, the interference level will be very much worse than if an efficient outdoor aerial is used. This is for two reasons:—

(*a*) The indoor aerial is to some extent screened by the building from the programme. The input of the wanted programme to the receiver, therefore, will be smaller with the inefficient indoor aerial.

(*b*) The indoor aerial, by virtue of the fact that it must necessarily be run in close proximity to conveyors of interference (electric power circuits, lighting circuits, telephone wiring, etc.), may actually pick up more interference than does the outdoor aerial.

From (*a*) and (*b*) above it will be seen that, in general, an indoor aerial both reduces the wanted programme and increases the strength of the unwanted interference. The effective ratio of programme to interference, is, therefore, less satisfactory than it need be. It is realized that in many cases efficient outdoor aerials cannot be used (large blocks of flats, landlord's restrictions, etc.), and therefore the aerial cannot always be installed in the most satisfactory way.

Again, many listeners wish to use a portable receiver so that they can take it from room to room. A portable receiver has a self-contained frame aerial which suffers from the same defect as the indoor aerial referred to above, since it operates under less favourable conditions of signal/noise ratio except in so far as its directive property may be utilized, as compared with the best possible signal/noise ratio at the receiver site. On the other hand, portable sets can be used to advantage where the interfering field is strictly localized—in addition, with some sets the directional reception properties of the frame aerial can be exploited in these circumstances.

Finally, there is a recent tendency to use the electric power mains as an aerial. This practice is to be deprecated (where interference is present) for the reasons stated above.

The earth lead from the receiver to the earthing point is an integral part of the aerial system of the receiver. If too long an earth lead is used, therefore, or one which is inefficiently run, there will be considerable loss in it which would tend to decrease the strength of the wanted programme and thus make the programme/noise ratio worse. There is, of course, also, the point that a badly run earth lead, or one with an inefficient earthing point, will pick up interference which can quite easily be reproduced by the receiver.

The Effect of using a Screened Receiver.

In recent years there have been considerable changes in the mechanical design of broadcasting receivers. The modern instrument is usually built on a metal chassis, with very small screened tuning coils and short runs of internal wiring. Thus, apart from the aerial and mains, the modern receiver is virtually screened from electrical interference, and usually its direct pick-up of interference will be appreciably less than that of the old-fashioned receiver built in a wooden cabinet with large unscreened coils and greater lengths of internal wiring. It should be pointed out, however, that in practice even an old-fashioned receiver has comparatively little pick-up of any radio-frequency waves—whether they be required programme or interference—unless a short length of aerial is attached to it. There is, therefore, little scope for improvement of the interference level by further screening the receiver.

The Range of Frequencies over which the Receiver will respond.

The range of frequencies—that is, ultra-bass to ultra-treble notes—which a receiver will reproduce depends on two factors in its design:—

(*a*) *Audio-frequency Amplifier Performance*:—Many of the noises created by electrical plant are composite sounds rich in high-frequency harmonics. If the audio-frequency band width of the receiver is limited at the top and/or lower register, there must be some reduction in the intensity of the interference it reproduces. For example, a low frequency which the audio-frequency amplifier of the receiver was incapable of reproducing, could not cause interference on its fundamental frequency, though interference might appear owing to harmonics of its fundamental frequency or to a modulation effect on the reproduction. Again if the components of the interference were of a sizzling (sibilant) type and the audio-frequency amplifier could not reproduce such high audio-frequencies properly, the level of interference would apparently be reduced, as the energy in its upper harmonics would be lost. Unfortunately, however, a low-frequency amplifier so limited in its ability to respond to high or low audio-frequencies would be quite intolerable for the reproduction of broadcast programmes.

(*b*) *Radio-frequency Band Width*:—In addition to the audio-frequency band width mentioned in (*a*) above, every broadcast receiver has a limited radio-frequency band width dependent on its " selectivity." To obtain high-quality reception of broadcasting, this band width should be not less than 16 kilocycles per sec., that is 8 kilocycles each side of the frequency to which the receiver is tuned. Actually, however, the shortage of ether channels available has caused designers of broadcast receivers to reduce the radio-frequency band width of their receivers from the desirable figure of 16 kilocycles to a compromise figure of the order of 10 kilocycles (that is 5 kilocycles each side) or less. This compromise is in order to obtain the necessary selectivity for the avoidance of interference from broadcasting stations on neighbouring ether channels. Though a selective receiver will give less interference than an unselective receiver, no further reduction of electrical interference can be obtained along these lines, as the selectivity of receivers has, for the reasons stated above, already been forced to the maximum limit.

The Effect of Different Types of Detector in the Radio Receiver.

The Research Department of the B.B.C. has recently carried out some simple tests on the behaviour of " Square-law " and " Linear " detectors in the presence of interference. These tests show that a " square-law " detector (anode bend) gives a noise voltage about two and a half times (8 decibels greater) that given by a " linear " detector (diode, power grid, etc.) when the interference is strong and there is no radio carrier. When both interference and carrier wave are present, there is no appreciable difference in the interference levels produced by these two systems of detection.

Straight or Superheterodyne Receiver Circuits.

If a superheterodyne receiver is compared with a straight receiver, both having the same overall frequency characteristic and magnification factor, there is no reason to believe that there is any difference between their performance from the electrical interference-level viewpoint.

Automatic Volume Control.

Most modern receivers are fitted with automatic volume control to maintain a constant input to the detector when there are wide variations in the strength of the required broadcasting signal (fading). Stated in another way, the overall magnification of the receiver is altered automatically in accordance with the strength of the signal to which it is tuned. When receiving a weak signal the gain of the set is automatically increased and, therefore, interference becomes more noticeable. This may lead the listener to think a set with automatic volume control is a worse producer of interference than one without it, but this is entirely a misconception. If the required signal field is less than one millivolt per metre, a receiver with automatic volume control may reproduce its programme at considerable strength but the interference level will be serious. It is for this reason that a minimum required signal strength to be protected was suggested.

Volume at which Reception is carried out.

The volume at which listeners like to listen varies over very wide limits. Owing to the shape of the sensitivity curve of the ear, it frequently occurs that the interference ratio when reception is at a low level appears to be very much more satisfactory than when at a high level. Thus, if the interference is weak compared with the required programme it may become inaudible if the level of both is reduced (threshold effect). This factor was taken into account in suggesting the suppression figure of 40 decibels.

Screened Leads-in for Aerials.

Recently, devices have come on the market based on the principle of placing the aerial outside the field of interference and connecting it to the receiver by means of an impedance-matched screened transmission line. This method of ameliorating the effects of existing interference is only applicable when the listener has some appreciable choice in a position for his aerial, a condition which does not exist in most cases for the town dweller in crowded districts or those living in flats. It frequently happens that in moving the active portion of the aerial out of the field of one interfering item it is moved into the field of another. These devices are effective when the interference is very localized and the aerial down-lead or lead-in has to pass through the field of the disturbance. The normal arrangement of this type of device is to mount a matching transformer at the top of the aerial mast with a second matching transformer very close to the aerial terminal of the receiver. The lead (transmission line) between the two matching transformers frequently takes the form of twin-wire lead-covered cable. Though these aerials do effect a considerable reduction in interference in certain cases, they have no influence on the signal/noise ratio at the aerial and, apart from this, there is the following difficulty in using them.

It has been stated above that impedance-matching transformers have to be used at both ends of the screened lead-in feeder. Though it is a comparatively simple matter to design impedance-matching transformers to work with any given transmission line on a particular

frequency or small band of frequencies, difficulties arise in attempting to make a single pair of matching transformers cover a wide band of frequencies. For maximum efficiency, even within the band of 200 to 2 000 metres a number of different matching transformers should be used. This is impracticable as one of the matching transformers is usually mounted at the top of an aerial mast; also it is unreasonable to expect the listener to use a number of aerials so that each pair of matching transformers would only have to cover a range of frequencies.

If, as is usual, only one pair of matching transformers be used and the maximum transference of energy from the aerial to the receiver is not attempted, the condition of decreasing the wanted signal without decreasing the unwanted signal would obtain. That is to say, the ratio of wanted signal to unwanted interference would be made worse, because the wanted signal would be lowered. Interference is sufficiently aperiodic in character to be unaffected in strength by the inefficient matching of the aerial and receiver to the transmission line.

The advertised selling prices in Great Britain of the several items of a commercial form of screened lead-in, with impedance-matching units, are as follows:—

	£	s.	d.
Two matching units..	1	5	0
Shielded twin cable, per yard ..	0	0	4½

REDUCTION OF INTERFERENCE AT THE RECEIVER.

(a) By means of Smoothing Circuits at the Receiver.

There seems little doubt that a receiver connected to the mains tends to give a value of signal/noise ratio less favourable than the same receiver operated by local batteries. This is for two reasons:—

(i) There is a tendency for the interference to travel along the mains and to pass into the receiver through the medium of its mains unit or by radiation off the mains unit and its connections to the receiver. The circuits of a mains-driven receiver which are liable to pick up interference are more closely coupled to the mains than need be the case when the receiver is operated by batteries.

(ii) Small variations arise, due to the switching of loads causing minor fluctuations in the power supply to the receiver. Though these are usually insufficient to be visible on, say, a lighting circuit, they frequently cause clicks, etc., in the receiver. A suitably designed filter circuit inserted at the point where the mains enter the receiver is, sometimes, a palliative to such interference. Many receiver manufacturers now fit high-frequency bypass condensers or screened mains transformers at the mains input to the receiver. It must be remembered, however, that no filter circuit at the point where the mains enter the receiver is of assistance if the interference is being radiated from the mains wiring in the house on to the aerial circuits of the receiver, which is the usual condition.

(b) By the Insertion of a Filter Device at the Point where the Mains enter the Listener's Premises.

In certain cases an improvement in the signal/noise ratio has been brought about by fitting an interference filter at the point where the electricity supply undertaking's mains enter the listener's premises. A filter circuit of this type prevents the interfering high-frequency currents from passing into the premises along the electric light wiring and subsequently reaching the receiver by radiation off the wiring on to the receiver's aerial system.

In the case of country houses fed from a public electricity supply by, say, buried mains, a device of this type might well prove of considerable assistance; but in cases such as blocks of flats it is unlikely that a filter at the mains input switch will be of much service, as the interference is being radiated from the electric wiring of adjacent flats in the block, the effect of which may be large compared with the effect of radiation off the wiring in the listener's own flat. It is also difficult in practice to arrange for a mains filter circuit to be installed at the actual point of entry of the mains, as these are usually sealed by the supply undertakings.

The cost of mains filters, such as are discussed above, varies over quite wide limits in accordance with the total peak load of the listener.

For example:—

The advertised selling prices of various commercial types of mains filters now on the market are quoted in the following table.

SELLING PRICES OF MAINS FILTERS.

Types of mains filter	Current-carrying capacity	Price
	amps.	
Condenser ..	—	10s. 6d.
Double high-frequency inductor and condenser	3	£3 5s. 0d.
	5	£4 10s. 0d.
	15	£5 5s. 0d.
	30	£7 0s. 0d.

In the majority of cases encountered in practice it has been found that a double-inductor-and-condenser type mains filter has to be used.

Since any particular receiver may be affected by radiation of the mains-borne currents flowing in the wiring of neighbouring premises, mains filters may require to be fitted in each of a number of adjacent houses, which may or may not be fitted with radio receivers, in order to remove the interference to a single receiver located in one of the houses.

Furthermore, each mains filter has to be capable of carrying without an appreciable voltage-drop the full load required by the premises in which it is installed.

Finally, as mains filter circuits of this type usually employ a condenser across the mains, high-grade condensers with an adequate over-potential test have to be used to avoid the serious difficulty which would be caused if even a small number were to break down on the mains side of the house main fuses. It will be appreciated that mains filters can do nothing towards suppressing any interference which originates on the listener's own premises—and that they have no effect on interference

which is directly radiated into the listener's premises, that is, not mains-borne.

General Comments.

It will be seen from the above that all possible steps which can be taken by the broadcast listener have little effect on the interference which is directly radiated on to his aerial system. It is well known that interference can reach a receiver in one of three ways: (1) by direct radiation only, (2) by mains-borne radiation only, and (3) by a combination of direct and mains-borne radiation. An attempt has been made in Great Britain to assess which of the above three mentioned is the most general cause of the interference which is experienced. On an analysis of the actual complaints investigated, it would seem that approximately half of the interference complaints are due to (2) above (mains-borne radiation only), but these figures are liable to be influenced by the fact that many listeners suffering from direct radiation do not complain, because they are fully aware of the identity of the interference and are under the impression that little can be done to assist them.

It would thus appear that it is in general preferable, on both economic and engineering grounds, to suppress the interference at its source rather than to allow it to be propagated and then to take what steps are possible to eliminate or reduce it at the many premises which it affects. For example, one item of plant may quite easily, by direct and mains-borne radiation, affect hundreds of broadcast listeners, each of whom would be involved in more expense in avoiding its effect than it would cost to fit a suppressor at the interfering item itself. Quite apart from the question of economics, the radiation of interference from the wiring of a neighbour who did not happen to be a broadcast listener, and who would therefore not take any steps to insert mains filters in his premises, is a contingency likely to be met with in practice.

APPENDIX II.

Report of the Meeting of the International Special Committee on Radio Interference held in Paris on June 28th, 29th, and 30th, 1934.

The following delegates were present at the meeting:—

International Electrotechnical Commission.

C. Le Maistre (General Sec.).
C. C. Paterson (Gt. Britain).
W. D. Owen (Gt. Britain).
R. T. B. Wynn (Gt. Britain).
A. Morris (Gt. Britain).
Johnstone Wright (Gt. Britain).
A. S. Angwin (Gt. Britain).
E. Divoire (Belgium).
M. Marchal (Belgium).
U. Ruelle (Italy).
R. Jouaust (France).
M. Milon (France).
Dr. Harbich (Germany).
Dr. Ewald (Germany).
Dr. E. W. Steidle (Germany).
Dr. Muller (Germany).
Dr. B. Van der Pol (Holland).
D. Zoeten (Holland).
G. Emmerik (Holland).

International Broadcasting Union.

R. Braillard (President of the Technical Commission).
P. Baize (French State Broadcasting Service).
L. W. Hayes (British Broadcasting Corporation).
Baron Van den Bosch (Belgian National Broadcasting Institution).

International Union of Producers and Distributors of Electrical Energy.

E. Brylinski (General Delegate).
M. de Valbreuze.

International Conference on Large High-Tension Electric Systems.

J. Tribot Laspière (General Delegate).

World Power Conference.

C. Rodgers.

International Union of Railways.

Dr. K. Apel (German State Railways).

Secretariat.

J. F. Stanley.
L. Ruppert.

M. Brylinski, President of the French Electrotechnical Committee, welcomed the delegates, and expressed the regret of Dr. Enström, President of the I.E.C., at his inability to be present.

M. Brylinski proposed, and it was unanimously agreed, that Mr. Paterson should be Chairman of the Committee for the present meeting.

The chief delegates introduced their colleagues, and certain documents which had not been previously circulated were distributed.

The Chairman suggested, and it was agreed, that, with a view to making as rapid progress as possible, the Committee should divide into two Sub-Committees as follows:—

Sub-Committee No. 1—Chairman, M. Raymond Braillard.
Sub-Committee No. 2—Chairman, Dr. Balth. Van der Pol.

The terms of reference of Sub-Committee No. 1 were as follows:—

> "To report on the desirable and/or practical numerical limit or limits to the interference with reception due to electrical apparatus and to formulate a recommendation."

The terms of reference of Sub-Committee No. 2 were as follows:—

> "To report on the most effective and practical method of measuring the interference from electrical apparatus which can be recommended to the different countries for their study and adoption as an interim step."

Sub-Committee No. 1, after having studied the reports presented by various delegates, reached an agreement upon the values corresponding to what may be regarded as "interference-free" broadcast reception. It was,

however, recognized that it was at present difficult and premature to fix definitely a practical value for international use for the degree of protection to be realized, and that it was desirable to continue experimental investigations on an international basis.

Sub-Committee No. 2, after having considered the various methods of measurement employed in different countries, which may be reduced to three different fundamental methods, the principles of which are described below, felt that it would also be desirable to undertake an experimental comparison of these methods with a view to establishing the relationship between them.

Consequently the Committee, in a Plenary Session, unanimously adopted the following resolutions:—

Section I.

(i) No protection is so far being considered in the case of wanted signals having a field of less than 1 millivolt per metre.

(ii) The interference should be considered relative to a wanted signal, the carrier wave of which is modulated to a mean depth of 20 per cent.

(iii) Taking into account exclusively the interests of broadcasting, it is desirable, if "interference-free" reception is to be obtained, that the level of the interference, measured in accordance with the methods which will be defined later, should be lower by 40 decibels than the mean level of the wanted signal defined above, i.e. of a field of 1 millivolt per metre modulated at 20 per cent.* It is assumed that the level of output of the loudspeaker is at least 40 decibels above the threshold of audibility of the ear at a frequency of 1 000 cycles per second.

Section II.

So far as present-day electrical installations are concerned, the degree of protection indicated in paragraph (iii) of Section I above cannot be assured to broadcast listeners, practical values proposed by different delegations being equivalent to 21, 21·5, and 30·5 decibels.†

It is admitted that, in the present state of the art, it would be difficult and premature to fix definitely a uniform practical value. It has been agreed to carry out some joint tests during a meeting which will be held in Berlin towards the end of October, 1934.‡ During these tests, a systematic comparison of methods of measurement and appraisement of interference will be made with a view to the determination of the values of protection which are practically attainable.

Section III.

The methods of measurement already applied in different countries for evaluating the relative magnitude of interference may be classified under three heads, as follows:—

(1) In the French method, the low-frequency currents produced at the loudspeaker terminals, by a test signal and by the disturbance, are measured successively by means of a standard receiver comprising a linear detector and amplifier.*

(2) In the German method (also used in Holland) the high-frequency voltage produced at the terminals of the interfering electrical appliance is measured, and the attenuation of the interference between the source and input terminals of a receiver is evaluated on the basis of statistical experimental data, thus enabling the interfering electromotive force applied to the receiver to be calculated.†

(3) In the British method, the vertical component of the high-frequency interfering field is measured at the site of the listener's receiving aerial. In order to ascertain the interference produced by a machine or any electrical appliance, the same component is measured at a number of points about 2 metres away from the machine or appliance.

Section IV.

For the purpose of international co-ordination, the comparison of these three methods cannot usefully be made except on an experimental basis. It has therefore been decided that in the course of the tests which will be made in Berlin, as stated in Section II above, the following matters will also be considered:—

(*a*) The establishment on a common basis of comparison of the results given by the three methods measuring the same disturbances.

(*b*) The possibility of one of these three methods or any other method being proposed for international use.

Section V.

It has been decided that a group of five experts, assisted by the General Secretary of the I.E.C. and including the Chairmen of the two Sub-Committees, a British delegate, a French delegate, and a German delegate, shall meet in Berlin on 29th October, 1934,‡ to proceed with the comparative tests mentioned above. These experts will draw up a report in due course which will be submitted to the Special Committee which will meet in Berlin at a date which has been provisionally fixed for the end of November, 1934.§

C. C. Paterson
A. S. Angwin
A. Morris
W. D. Owen
C. Rodgers
Johnstone Wright
R. T. B. Wynn
} British Delegates.

* The signal/interference ratio may be measured either at high frequency or at low frequency, provided that the overall response of the receiver is linear.

† Assuming that the interfering field is equivalent to a sinusoidal field modulated at 100 per cent, these values correspond under certain assumptions to field strengths of 18, 16·6, and 6, microvolts per metre respectively.

‡ Postponed *sine die.*

* In the method at present used in France, the standard receiver is, in addition, provided with a network which corrects the low-frequency characteristic so as to simulate the sensitivity curve of the ear.

† A knowledge of the effective height of the listener's receiving aerial is an essential feature of the German method.

‡ Postponed *sine die.*

§ *Ibid.*

REPORT OF THE COUNCIL FOR THE YEAR 1933–1934, PRESENTED AT THE ANNUAL GENERAL MEETING OF THE 10TH MAY, 1934.

The Council, at the Sixty-Second Annual General Meeting of The Institution of Electrical Engineers, present to the members their Report for the year 1933–34, covering approximately the period from the 1st April, 1933, to the 31st March, 1934.

The continued progress of the Institution during the period under review affords much satisfaction to the Council. In this connection they desire to express their grateful thanks to those members who by their generous devotion of time and expert knowledge to the work of the various Committees of the Institution, and in other directions, assist so greatly in the achievement of its objects and the extension of its influence.

(1) Membership of the Institution.

The changes in the membership since the 1st April, 1933, are shown in a table included in Appendix A.

The following table shows the net growth of membership for the last 10 years:—

Year	Membership	Increase
1925	11 743	+ 328
1926	12 142	+ 399
1927	12 647	+ 505
1928	13 043	+ 396
1929	13 561	+ 518
1930	14 200	+ 639
1931	14 670	+ 470
1932	14 884	+ 214
1933	15 149	+ 265
1934	15 619	+ 470

(2) Honorary Member.

The Council have pleasure in recording that, as announced at the Ordinary Meeting on the 1st February, 1934, they have elected Dr. René Thury to be an Honorary Member of the Institution.

(3) Faraday Medal.

The twelfth award of the Faraday Medal was made by the Council to Sir Frank E. Smith, K.C.B., C.B.E., D.Sc., F.R.S.

(4) Honours and Distinctions Conferred on Members.

Barony.
Newton, Sir Douglas (Companion).

Baronetcy.
Pybus, Percy John, C.B.E., M.P. (Member).

K.C.V.O.
Glazebrook, Sir Richard Tetley, K.C.B., D.Sc., F.R.S. (Honorary Member).

Knighthood.
Yarrow, Harold Edgar (Companion).

C.M.G.
Brown, Harry Percy, M.B.E. (Member).

Chevalier of Dannebrog (Denmark).
Fraenkel, Poul Hermann, B.E. (Member).

(5) Mr. F. W. Crawter.

As a mark of appreciation and of recognition of Mr. F. W. Crawter's valuable services over an extended period of years as a member of the Institution's Membership Committee, the Council subscribed privately to the purchase of a presentation piece which will be handed to him by the President at a dinner following the Kelvin Lecture, on the 26th April, 1934.

(6) Institution Staff.

Mr. R. H. Tree retired on pension from the position of Chief Clerk on the 30th June, 1933. The Council desire to place on record their deep appreciation of his great services to the Institution during a period of 46 years.

It has been a pleasure to the Council to appoint Mr. F. W. Hewitt and Mr. A. E. Rayner, who have been on the staff of the Institution for 21 years and 34 years respectively, to be Assistant Secretaries of the Institution, in recognition of their long and efficient services.

On the 1st February, 1934, Mr. Rowell completed 25 years of service as Secretary. Prior to his appointment as Secretary, he had been successively Secretary's Chief Assistant and Assistant Secretary for a period of 8 years, his total length of service therefore being 33 years. It is interesting to recall that at the time when Mr. Rowell was appointed as Secretary the total membership of the Institution was 6 068, as compared with the present total of 15 619. The Council take this opportunity of expressing their great appreciation of his services and devotion to the interests of the Institution.

(7) Deaths.

The Council regret to have to record the death of the following 78 members of the Institution during the year:—

Members.

Andrews, O. M.
Bowden, J. H.
Cotsworth, W.
Cross, E.
Crowe, Colonel P. B.
du Pasquier, A. E.
Ellis, T. W.
Everest, A. R.
Frain, W.
Hatton, R. J.
Henderson, Dr. J.
Holmes, L. W.
Legros, L. A., O.B.E.
Mackness, C. F.
Manville, Sir E.
Orsettich, R.
Otagawa, M., M.E.
Perrow, W. H.
Preston, K.
Ranken, A. W.
Ridley, H. W.
Riseley, H. L.
Roberts, J. E.
Royce, Sir F. H., Bart., O.B.E.
Rudd, J. A.
Schofield, S. D.
Sparks, H. C., C.M.G., D.S.O., M.C.
Stewart, A. W.
Trant, L. B.
Varley, C. O.

Associate Members.

Batty, D. E.	Jenkins, R. L.
Briggs, F. H.	Jones, H. W.
Buswell, W. N.	Lilleker, J. R.
Challans, E. W., B.Sc. (Eng.).	Lucas, E.
Chenevix-Trench, L. G.	McArthur, R. T., D.S.O.
Davies, H. O.	McCourt, R.
Davies, L. H., M.C.	MacSheehy, J. G.
Eunson, D. M.	Meade, J. H.
Ford, C. R.	Miller, L. B.
Gibbins, G. M.	Morgan, P. D., M.Sc.(Eng.).
Glegg, Sir A.	Ramsay, K. M. A.
Gregson, P. E.	Raven, T. F.
Hepworth-Collins, W.	Reame, A.
Hoffe, J. A.	Robinson, C.
Hotz, H.	Stewart, J. H.
Illingworth, J. P.	Wilson, R. M.

Companion.

Blundell, J. W.

Associates.

Aiyar, A. K.	Tointon, W. N. H.
Ford, F. W.	Webb, L.

Graduates.

Brooksbank, R. J., B.Sc.	Evans, A. E., B.Sc.
Chaudhuri, J. D., B.Sc. Tech.	Nunn, R. T.
	Walker, E. H., B.Sc.

Students.

Corkhill, A. J.	Raman, M. I., B.A.
Diggins, E. A.	Sheriff, D. W. D.
Godwin, E. W. D.	Wall, C. A.

(8) Council Ballot. Canvassing for Votes.

It is desired to remind members that the Council strongly deprecate organized canvassing, by means of circulars or otherwise, in favour of those nominated for election to the Council.

Consideration will be given at the next revision of the Bye-laws to the submission to the members of a new bye-law which will disqualify nominees in favour of whom organized canvassing has taken place.

(9) Examinations.

Graduateship Examinations were held in May and November, 1933, in London, Belfast, Birmingham, Cardiff, Dublin, Glasgow, Loughborough, Manchester, Newcastle-on-Tyne, Norwich, and Southampton, and also, in November only, in Ceylon, China, Egypt, Federated Malay States, India, Malta, New Zealand, Palestine, and South Africa.

In addition, a number of candidates were permitted to fulfil the educational requirements for Associate Membership by the submission of satisfactory papers or theses in lieu of the Examination.

Mr. J. Burrows was awarded the Page Prize (value £4 4s.) for the thesis submitted by him, his subject being "The Design of Heavy A.C. Conductors."

(10) National Certificates and Diplomas in Electrical Engineering.

England and Wales.—In 1933 the Joint Standing Committee, representing the Board of Education and the Institution, was associated with the final examinations of 170 courses at colleges and schools in England and Wales, approved in connection with the above certificates and diplomas.

The final examinations were held during the summer of 1933, and the number of awards was as follows:—

707 Ordinary Certificates.
347 Higher Certificates (including 28 Post-Higher Certificates).
28 Ordinary Diplomas.
12 Higher Diplomas.

Scotland.—In conjunction with the Scottish Education Department, the Institution was associated with 14 courses in Scotland during the year under review.

The final examinations were held during the summer, and the number of awards was as follows:—

13 Ordinary Certificates.
17 Higher Certificates.
10 Higher Diplomas.

(11) Scholarships.

The following Scholarships have been awarded by the Council during the Session:—

Ferranti Scholarship.
(Annual Value £250; tenable for two years.)
No award.

Duddell Scholarship.
(Annual Value £150; tenable for three years.)
H. Haywood (Staveley Grammar School).

Silvanus Thompson Scholarship.
(Annual Value £100, plus tuition fees; tenable for two years.)
P. L. Olsen (Messrs. C. A. Parsons & Co., Ltd.).

Swan Memorial Scholarship.
(Value £120; tenable for one year.)
D. A. Bell, B.A. (Magdalen College, Oxford).

David Hughes Scholarship.
(Value £100; tenable for one year.)
R. C. Barton (University College, Cardiff).

Salomons Scholarship.
(Value £100; tenable for one year.)
R. S. Quick (Bristol University).

Paul Scholarship.
(Annual Value £50; tenable for two years.)
R. P. Kinsey (Wandsworth Technical Institute, London).

Thorrowgood Scholarship.

(Annual Value £25; tenable for two years.)

L. F. Tuff (London and North-Eastern Railway).

War Thanksgiving Education and Research Fund (*No.* 1).

The Council have made grants from the above Fund for research purposes as follows:—

£50 each to:—R. G. Armstrong (University College, London). D. H. R. Whyman (Sheffield University).

With the exception of the Paul Scholarship, which is awarded in alternate years only, all the above scholarships and grants may be awarded annually.

(12) Institution Building.

As in former years, the free use of the Institution premises has been granted to a number of kindred societies in connection with their meetings, and 211 such meetings were held during the past year.

The whole of the office accommodation released by the removal of the British Broadcasting Corporation from the building has since been let to other bodies, and the following is a complete list of the tenants of the Institution:—

British Electrical Development Association.
British Electrical and Allied Industries Research Association.
Electric Lamp Manufacturers' Association.
The Institute of Transport.
National Register of Electrical Installation Contractors (will shortly commence occupation).

(13) Meetings.

During the past twelve months, 540 meetings were held in London and at the Local Centres by the members, the Council, and the various Committees. A detailed statement is given in Appendix B.

(14) Premiums.

The Premiums awarded by the Council for papers read at meetings or accepted for the *Journal* will be announced about the time of the Annual General Meeting.*

(15) Local Centres and Sub-Centres.

The attendances and proceedings at the meetings of the Local Centres and Sub-Centres continue to maintain their high standard.

The President attended functions and meetings at the Centres at Cardiff, Glasgow, Leeds, Liverpool, Manchester and Newcastle-on-Tyne, as well as at the Sheffield and Tees-Side Sub-Centres, and he will be present at a meeting in Dublin to be held in May. He was represented at the Annual Dinner of the South Midland Centre at Birmingham by Mr. J. M. Kennedy, Vice-President.

At each of the places so far visited the President addressed the members present and was much impressed by the activities of these branches of the Institution and by their inestimable value in extending its influence and its prestige.

Full details of the meetings and other activities of the Local Centres and Sub-Centres are contained in the Annual Reports presented each year to the local members.

(16) Activities of Overseas Members.

The Overseas Activities Committee of the Council are very gratified at the continued increase in the activities of the Institution overseas.

In addition to the activities of the Argentine and China Centres, details have been received of social gatherings and of meetings for the reading and discussion of papers, arranged by the various Local Committees, which have been held with success in Queensland, Victoria, Western Australia, and at Bombay and Lahore.

In several instances papers already read in London have been read and discussed, while in other cases papers have been written and presented by local members.

The second Annual Conversazione and Reunion of members from overseas, and their ladies, was held in the Institution building on Wednesday, 12th July, 1933, the total attendance being over 140. An account of the proceedings was published in the *Journal* for September, 1933 (vol. 73, page 318).

The Council have recently adopted proposals put forward by the Engineering Association of Malaya for a scheme of co-operation between the Institution and the Association, by means of which it is hoped that the activities of electrical engineers in Malaya in regard to meetings, etc., may be encouraged.

Under this scheme the Association has been appointed as the Institution's official representative for British Malaya, and a Committee consisting of members of the Institution and, if deemed desirable, of other engineers engaged in electrical engineering is being formed by the Association. The main function of this Committee will be to arrange for the reading and discussion of papers either at ordinary section meetings of the Association, or at special meetings held at one or other of the Association's four centres, whose headquarters are at Kuala Lumpur, Ipoh, Singapore, and Penang.

(17) Exchange of Greetings between London and Bombay.

At the suggestion of the Bombay Local Committee, an exchange of greetings took place, by means of wireless telephony, on Tuesday, 16th January, 1934, between the President, Mr. P. V. Hunter, in London, and Mr. F. O. J. Roose, the Chairman of the Local Committee, in Bombay. The occasion was that of a meeting of local members in the Bombay district at which a paper on the subject of "The Indian Beam Wireless System" by Mr. W. H. Ashley, Director of Beam Stations in India, was read and discussed. A full account of the event was published in the issue of the *Journal* for February, 1934 (vol. 74, p. 199).

* See vol. 74, p. 602, and vol. 75, p. 130.

(18) Local Honorary Secretaries Abroad.

During the Session, the Council appointed Dr. F. A. Gaby as Local Honorary Secretary of the Institution for Canada in place of Mr. Lawford S. F. Grant, who has retired from this office.

(19) Wireless Section.

The interest and activities of the Wireless Section, whose membership is 643, continue to be well maintained. Eight meetings have been held during the past year, at which 7 papers were read, and one discussion took place on " The Interference of Electrical Plant with the Reception of Radio Broadcasting." In addition, 15 papers have been published or accepted for publication in the *Journal*. The average attendance at the meetings was 157, as compared with 135 for last session.

The Committee have decided to introduce a new feature into the Section's activities by holding a Summer Meeting in 1934, and arrangements have been made to visit the National Broadcasting Station at Droitwich on Saturday, 26th May.

(20) Meter and Instrument Section.

The membership of the Meter and Instrument Section is now 607. Eight meetings have been held during the past year, the average attendance being 83, which compares with 95 during the preceding 12 months. The meetings, which included an informal debate, were most successful, and the papers read raised keen and interesting discussions.

The Summer Visit for 1933 took place on Saturday, 6th May, when a party consisting of about 100 members and ladies visited Hampton Court Palace and the National Physical Laboratory, Teddington. The visitors enjoyed the hospitality of the Director of the Laboratory, Sir Joseph E. Petavel, K.B.E., D.Sc., F.R.S., and inspected the various departments. The visit proved most enjoyable and thanks have been accorded to Sir Joseph Petavel for the excellent arrangements made for the reception of the party.

The Section Dinner was held on the 15th November, 1933, the attendance being 130.

(21) Transmission Section.

As a result of negotiations with the Overhead Lines Association, the Council have approved a scheme drawn up by the General Purposes Committee for the formation of a " Transmission " Section of the Institution, which will as far as possible take the place of the Association and be similar in character to the existing Wireless and Meter and Instrument Sections. Any member of the Institution wishing to become a member of this Section will be required to satisfy its Committee that he is actively engaged in the study, design, manufacture, construction, maintenance, or operation of transmission and distribution lines, both overhead and underground. On the formation of the Section, all members of the Overhead Lines Association who are already members of the Institution will automatically become members of the Section and form its nucleus.

It is contemplated that the final details will be completed shortly and that it will be possible for the new Section to commence to function at the beginning of next Session.

(22) Informal Meetings.

Twelve meetings have been held during the year, the average attendance being 88, as against 101 last year.

The Informal Meetings Committee again cordially invite members to write to the Secretary indicating subjects which they wish to suggest for discussion. Offers from members to open discussions will also be welcomed and carefully considered by the Committee.

(23) Students' Sections.

The nine existing Students' Sections of the Institution have carried out during the session a very full programme of meetings, visits to works, and social functions, and full details and accounts have been given from time to time in the *Students' Quarterly Journal*.

The actual membership of the nine Sections is in the aggregate 3 470, which includes some 1 500 Graduates under the age of 28, who are entitled under the Bye-laws to the same privileges as Students.

The " Students' Lectures " were delivered this session by Mr. F. H. Clough, C.B.E., and Mr. R. O. Kapp, at the places indicated:—

Lecturer.	*Subject.*	*Place.*
Mr. F. H. Clough, C.B.E.	" Domestic Electrical Apparatus from an Engineering Point of View "	Edinburgh } Scottish Section Glasgow } Leeds Newcastle-on-Tyne Sheffield
Mr. R. O. Kapp	" Engineering Problems of the Grid "	London Birmingham Bristol Liverpool Manchester

The total attendances at the 10 Lectures were approximately 660, compared with 640 for the 10 Lectures given last session by other lecturers.

The third Annual Meeting of the Honorary Secretaries of the Sections was held in London on the 16th February, 1934, when a very useful and interesting discussion took place on points of organization and routine.

The Students' Section Summer Tour, which was to have taken place in Holland and Germany in August, 1933, had to be cancelled, the number of intending participants being insufficient to warrant holding the meeting.

It is noted that there are still some Students who do not take the necessary steps to transfer to the class of Graduates after complying with the Institution's Examination Regulations. The importance of transferring cannot be too greatly emphasized, especially as, since the Bye-laws were last revised, the title " Graduate I.E.E." has a definite status. The only steps which the qualified Student is required to take are to apply for transfer on the authorized form " GS " (which can be obtained from the Secretary), and in the case of those who have not passed the I.E.E. Graduateship Examina-

tion, to submit evidence that they possess an exempting educational qualification. The transfer does not entail any entrance fee or additional subscription.

It is of interest to record that Mr. H. T. Young, Vice-President, has presented a Trophy to be competed for annually at a sports contest between the London I.E.E. Students' Section and the Students' and Graduates' Sections of the Institutions of Civil and Mechanical Engineers. The contest will be on similar lines to that organized in 1933, when the London Students' Section accepted a challenge by the "Civils" and "Mechanicals" jointly, as a result of which a very enjoyable day of cricket and lawn tennis was spent. The presentation of the Trophy will regularize the procedure for future years and will, it is felt, lead to an increasingly happy co-operation between the junior Sections of the three Institutions, who have already for some years participated in joint meetings in London at which papers of common interest have been read and discussed.

The *Students' Quarterly Journal*, now published as a true quarterly, continues to receive good support. Articles have been published on a wide range of subjects, which make interesting reading. As a general rule highly technical articles are avoided, a policy which seems to meet with general approval, and in several instances it has been possible to provide simple but authoritative articles dealing with new developments, thus helping to keep Students and Graduates in touch with current events.

(24) Faraday Lecture.

The Faraday Lecture this session was delivered by Mr. Clifford C. Paterson, O.B.E., who chose as his subject "The Electrical Engineer and the Free Electron." The Lecture was given at Leeds, Liverpool, London, Loughborough, Manchester, Newcastle-on-Tyne, and Newport, and will also be given at Dublin and at Dundee before the session closes.

The 7 Lectures so far delivered this session have been attended by a total audience of approximately 3 900, of whom over 3 000 were non-members. The corresponding figures for 7 Lectures delivered in the previous year were 4 590 and 3 810 respectively.

(25) Reviews of Progress

Continuing the series of reviews of progress in electrical engineering which have appeared in the *Journal* each year since 1926, reviews on the following subjects have been, or will be, published during 1934:—

Electrical Measuring Instruments, other than Integrating Meters.
Electro-Medical and Radiological Apparatus.
Integrating Electricity Meters.
Transmission and Distribution.

Arrangements have been made for reviews on the following subjects in 1935:—

Power Stations and their Equipment.
Radio-Telegraphy and Radio-Telephony.
Telegraphy and Telephony.

(26) Anniversary Celebrations and Conferences.

During the year under review, the Institution has been represented at Anniversary Celebrations and Conferences, etc., arranged by other bodies as shown in the following table:—

Name of Body	*Nature and Date of Function*	*Name of I.E.E. Representative*
Association of Teachers in Technical Institutions	Annual Conference, Lincoln (3–6 June, 1933)	J. Paley Yorke
Royal Cornwall Polytechnic Society	Centenary Celebrations, Falmouth (18–21 July, 1933)	L. A. Hards
Royal Sanitary Institute	Annual Congress, Blackpool (17–24 June, 1933)	C. Furness
Société Française des Électriciens	50th Anniversary Celebrations, Paris (23–25 November, 1933)	P. V. Hunter, C.B.E. (President) P. F. Rowell (Secretary)
Trevithick Centenary Committee	Trevithick Centenary Commemoration (April, 1933)	Roger T. Smith (Past President)

In the case of the Société Française des Électriciens, an Address of Congratulation was presented by the delegates on behalf of the Institution. A Congratulatory Address was also sent to the Elektrotechnischer Verein of Austria on the occasion of its Jubilee Celebrations, held in Vienna on the 5th April, 1933.

(27) Paris International Conference on Large E.H.T. Supply Systems.

The seventh session of the above Conference took place in Paris from the 16th to the 24th June, 1933. The number of countries represented was 32, Great Britain having 34 representatives. The delegates appointed by the Institution were Mr. E. B. Wedmore (chief delegate) and Dr. E. H. Rayner.

(28) Summer Meeting.

The Council accepted a cordial invitation from the Committee of the Western Centre for a Summer Meeting to be held in the area of that Centre in 1933, and the Committee arranged an interesting programme for the occasion. Unfortunately, the response from members was disappointing and, as it became clear that the number of participants would fall short of the minimum desirable if the Meeting was to be a success, it was decided to cancel the arrangements.

No arrangements are being made for a Meeting for 1934, but consideration is being given to the possibility of organizing one to take place during the summer of 1935.

(29) Annual Conversazione.

The Annual Conversazione was held on the 22nd June, 1933, at the Natural History Museum, London. The total attendance of members and guests was 2 115.

(30) Annual Dinner.

The Annual Dinner was held at Grosvenor House, Park Lane, London, on the 8th February, 1934, when 784 members and guests were present.

An account has been published in the *Journal* (vol. 74, p. 372).

(31) Library.

During the year, 251 books and pamphlets were presented to the Reference Library by members and others, and 102 volumes were purchased. The total number of readers for the year was 6 816, of whom 488 were non-members, as against 7 190 and 407 respectively in 1932–33.

Ninety-three new volumes were added to the Lending Library and 3 167 books were issued to 1 260 borrowers, the corresponding numbers for the previous year being 2 828 and 1 077 respectively.

(32) Gifts to the Institution.

The Council express their cordial thanks to the donors of the following gifts to the Institution:—

Donor.	*Gift.*
Mr. W. O. Smith and Mr. W. S. Smith	Case containing the original bars of selenium used by Willoughby Smith in the discovery of light-sensitive properties of selenium.
Mr. P. Rosling ..	Four framed water-colour sketches illustrating incidents connected with the laying of the Atlantic Cable of 1865.
Baron A. Danvers ..	Framed portrait of the late Mr. F. C. Danvers (the Institution's Honorary Auditor, 1892–1906).

(33) Oil Paintings.

The Council are glad to be able to record the addition to the Institution's collection of oil paintings of a portrait of the late Hon. Sir Charles Algernon Parsons, O.M., K.C.B., F.R.S. This portrait, which was presented by The Rt. Hon. The Viscount Falmouth, is a copy by M. Ayoub of one by Sir William Orpen, which hangs in the Laing Art Gallery, Newcastle-upon-Tyne.

(34) Speaking Films of Eminent Electrical Engineers.

Through the generosity of private donors the Council have been able to arrange for the making of speaking films of eminent electrical engineers. A film has already been made of Sir John Ambrose Fleming, M.A., D.Sc., F.R.S.

(35) Sir Charles Parsons Memorial.

With the approval of the Council, the then President, Prof. E. W. Marchant, D.Sc., signed in April, 1933, an appeal for subscriptions towards a memorial of the late Sir Charles Parsons. The appeal was issued to members of the leading Institutions in March, 1934, and it was accompanied in the case of this Institution by a letter from the President recommending the appeal to the sympathetic consideration of the members.

The Joint Committee dealing with the matter have decided that the memorial shall take the following forms:—

(1) A memorial in Westminster Abbey.
(2) An annual lecture, in any of the subjects in which Sir Charles Parsons was interested, to be delivered by a distinguished man of any nationality.
(3) A Library at London House to be called the "Parsons Research Library," which will also contain a bust of Sir Charles.

(36) "Science Abstracts."

The Physics volume of *Science Abstracts* for 1933 contains 5 491 abstracts, as compared with 5 364 in 1932. The Electrical Engineering volume contains 3 078 abstracts, as compared with 2 926.

The publication, which appears monthly in two sections, namely, Section "A" (Physics) and Section "B" (Electrical Engineering), consists of full abstracts from the leading scientific and technical journals and the proceedings of learned societies of the whole world, and presents in a form convenient for immediate reference a complete and concise record of the progress of physical science and electrical engineering. 1 405 members of the Institution subscribe to *Science Abstracts*, 817 subscribing to both Sections and 588 to Section "B," but the Council earnestly hope that more members will become subscribers to the publication, in view of its exceptional value. It may be obtained, if ordered in advance, by Students of the Institution, as well as by Graduates under the age of 28, at the special rate of 7s. 6d. per annum for both Sections, or 5s. for either the Physics or the Electrical Engineering Section, and by all other members of the Institution at 20s. for both Sections, or 12s. 6d. for either Section alone, the rates charged to the general public being £1 15s. per Section, or £3 for both Sections.

(37) Model General Conditions for Contracts.

The proposed set of Model Conditions "E" for the supply, laying and erection of electric mains (overhead and underground), for home contracts, is still under consideration.

(38) Regulations for the Electrical Equipment of Buildings.

The Wiring Regulations Committee have practically completed the revision of the Ninth Edition of the Regulations, and it is hoped to issue the Tenth Edition within the next few months.

The Council are especially gratified at the official recognition of the I.E.E. Wiring Regulations by the Electricity Commissioners in the new Electricity Supply Regulations.

(39) Regulations for the Electrical Equipment of Ships.

The Committee intend to bring the above Regulations up to date as soon as the Tenth Edition of the Wiring Regulations (Buildings) is issued.

(40) Committee on Overhead Lines.

Two meetings of this Committee have been held, at which the following question was considered:—Whether the types of earthing bar fixed to poles are really effective

in the event of a line breaking—a knowledge of which can only be gained by actual tests. Arising out of the discussion on this question the Electrical Research Association were asked to undertake tests to provide data, and the results of these tests are now being considered by the Committee.

(41) COMMITTEE ON ELECTRICAL INTERFERENCE WITH BROADCASTING.

The Council have appointed the above Committee, representative of the whole of the industry and under the chairmanship of Mr. Clifford C. Paterson, to consider the memorandum prepared by the Committee mentioned in the Council's last Report. A number of Sub-Committees have been set up, dealing respectively with Domestic Apparatus, Larger Electrical Plant, Traction, Automobiles and Aircraft, Suppression at Consumers' Premises, and Specification Drafting. Reports from the first five of the above-mentioned Sub-Committees have been approved by the Main Committee. A Specification Drafting Sub-Committee is now engaged, with the co-operation of the British Standards Institution, in preparing a specification with the object of correcting radio interference from appliances used in or about listeners' premises, the specification to cover components, methods of test, etc.

In addition, the International Electrotechnical Commission has recently set up a Special Committee to deal with the question of international action in regard to electrical equipment embodying suppression devices, and the Institution Committee have been invited, and have agreed, to act for the British National Committee of the International Electrotechnical Commission in this matter.

(42) CONFERENCE OF JOINT ELECTRICITY AUTHORITIES, JOINT ADVISORY BOARDS, AND JOINT COMMITTEES.

The Council have decided that the Institution should recognize the above Conference as the representative organization in connection with matters dealt with by the organizations mentioned in its title.

(43) BENEVOLENT FUND.

The Committee of Management of the Benevolent Fund of the Institution report that on the 31st December, 1933, the total assets of the Fund amounted to £23 106 10s. 7d., of which £20 291 15s. 8d. was on Capital Account, and £2 814 14s. 11d. in respect of unexpended income. The donations and subscriptions to the Fund in 1933 amounted to £2 635 18s. 3d., in which amount are included the proceeds of Golf Competitions organized by the Mersey and North Wales (Liverpool) Centre (£63 17s. 6d.) and the North-Western Centre (£50). In addition to the foregoing, a gift of £219 8s. 4d., being accumulated surplus on past Balls, was received from the General Committee for the Electrical Engineers' Ball. The Fund also benefited by the surplus of £224 3s. 4d. on the 1933 Ball, and gifts were received from the organizers of similar functions in the provinces (£52 10s. from the South Midland Electrical Engineers' Ball, and £35 from the Ball arranged by the North Midland Centre). Full details are shown in the Accounts of the Fund for 1933.

In the course of 1933, grants were made to 53 persons, amounting to a total of £2 599 15s. 3d. During the last few years the annual totals of the grants made have shown a marked increase.

The Council earnestly desire to bring the Fund to the notice of all the members of the Institution. At present 30 per cent of the members subscribe to the Fund, and the Council appeal to the remaining members to send donations or promises of annual subscriptions of any amount, which will be gratefully received.

Electrical Engineers' Ball.

The Ball held at Grosvenor House, Park Lane, on Friday, the 9th February, 1934, was the second of these functions to be held under the auspices of the Institution's Benevolent Fund. It was most successful, and the Fund benefited by receiving the whole of the surplus of £209. Cordial thanks are due to the General and Executive Committees of the Ball and to the stewards for their valuable assistance.

(44) SUMMARY OF ANNUAL ACCOUNTS.

Income and Expenditure.—The surplus on the Revenue Account for the year ended 31st December, 1933, is £4 997 16s. 6d. This amount has been carried to the Balance Sheet, and compares with a surplus of £7 827 17s. 8d. in 1932.

Surplus of Assets over Liabilities.—Taking the investments at cost and the Institution building and lease, the library and furniture, etc., at the values standing in the books after writing off depreciation—

	£	s.	d.
the Assets amount to	205 298	10	10
against Liabilities	10 896	12	9
leaving a surplus of	194 401	18	1
which, in comparison with that of the year 1932, viz.	189 814	1	2
shows an improvement of	£4 587	16	11

The surplus of £194 401 18s. 1d. referred to above is made up as follows:—

				£	s.	d.
Assets.						
Institution building and lease				73 028	6	10
Investments, cash, etc. ..				124 767	2	5
Stock of paper, libraries, and furniture				7 503	1	7
				£205 298	10	10
Less *Liabilities.*						
Trust Fund Accounts ..	330	12	4			
Sundry creditors ..	6 791	18	2			
Repairs Suspense Account	3 409	16	4			
Subscriptions received in advance	364	5	11			
				10 896	12	9
				£194 401	18	1

Investments.—The investments made during the year were as follows:—

	£	s.	d.
£2 005 3s. 3d. 3½ % War Stock, cost ..	1 991	11	7
£1 000 Nyasaland Government 4½ % Guaranteed Stock (1952–72), cost ..	1 142	13	0
	£3 134	4	7

(45) The Institution and Bodies on which it is Represented.

Appendix C (page 815) shows in diagrammatic form the organization of the Institution and the bodies on which it is represented.

APPENDIX A.

Membership of the Institution.

The changes in the membership since the 1st April, 1933, are shown in the following table:—

	Hon. Mem.	Mem.	Assoc. Mem.	Com.	Assoc.	Grad.	Stud.	Total.
Totals at 1 April, 1933	14	1 967	5 956	112	1 450	2 862	2 788	15 149
Additions during the year:—								
Elected ..	1	1	128	3	58	276	785	1 252
Reinstated	—	2	7	—	3	2	6	20
Transferred to ..	—	55	254	—	5	418	—	732
Totals..	1	58	389	3	66	696	791	2 004
Deductions during the year:—								
Deceased ..	—	30	32	1	4	5	6	78
Resigned ..	—	17	49	4	17	38	69	194
Lapsed ..	—	8	52	1	74	60	335	530
Transferred from ..	—	—	55	—	26	211	440	732
Totals..	—	55	188	6	121	314	850	1 534
Net Increase ..								470
Totals at 1 April, 1934	15	1 970	6 157	109	1 395	3 244	2 729	15 619

APPENDIX B.

Meetings.

The following is a list of the meetings held during the past 12 months:—

Ordinary Meetings ..	17
Annual General Meeting ..	1
Annual General Meeting (Benevolent Fund)	1
Wireless Section ..	8
Meter and Instrument Section ..	8
Informal Meetings ..	12
Council Meetings ..	15
Local Centres:—	
Irish ..	7
Mersey and North Wales (Liverpool)	11
North-Eastern ..	15
North Midland ..	12
North-Western ..	13
Scottish ..	13
South Midland ..	10
Western ..	8
Local Sub-Centres:—	
Dundee ..	7
East Midland ..	8
Hampshire ..	8
Sheffield ..	7
Tees-Side ..	8
West Wales (Swansea) ..	6
Students' Sections:—	
Bristol ..	11
Liverpool ..	11
London ..	15
North-Eastern ..	11
North Midland ..	10
North-Western ..	10
Scottish ..	12
Sheffield ..	8
South Midland ..	11
Committees:—	
Benevolent Fund ..	11
Earthing to Water Mains ..	2
E.H.T. Conference, Paris (British National Committee)	3
Committees—*continued.*	
Electrical Engineers' Ball ..	4
Electrical Interference with Broadcasting (and Sub-Committees) ..	32
Examinations ..	8
Finance ..	9
General Purposes (and Sub-Committee) ..	11
Informal Meetings	5
International Relations (and Sub-Committee) ..	3
Local Centres ..	1
Membership ..	7
Meter and Instrument Section (and Sub-Committees)	15
Model General Conditions ..	1
National Certificates (England)	5
National Certificates (Scotland)	2
Overhead Lines ..	2
Overseas Activities	1
Papers (and Sub-Committees) ..	10
Scholarships ..	2
"Science Abstracts" (and "Physics" Panel) ..	7
Ship Electrical Equipment ..	1
Wireless Section (and Sub-Committees) ..	19
Wiring Regulations (and Sub-Committees) ..	70
Other Committees	15
Total ..	540

APPENDIX C.

THE INSTITUTION OF ELECTRICAL ENGINEERS.

- Ordinary Meetings
- Wireless Section Meetings
- Meter and Instrument Section Meetings
- Informal Meetings
- Meetings of London Students' Section

COUNCIL.

Local Centres.

- Argentina
- China
- Irish
- Mersey and North Wales (Liverp'l)
  - Mersey and North Wales (Liverp'l) S.S.
- North-Eastern
  - Tees-Side S.C.
  - North-Eastern S.S.
- North Midland
  - Sheffield S.C.
  - North Midland S.S.
  - Sheffield S.S.
- North-Western
  - North-Western S.S.
- Scottish
  - Dundee S.C.
  - Scottish S.S.
- South Midland
  - East Midland S.C.
  - South Midland S.S.
- Western
  - West Wales (Swansea) S.C.
  - Bristol S.S.
- Hampshire S.C.

NOTE:—S.C. denotes a Sub-Centre, and S.S. a Students' Section.

COMMITTEES OF COUNCIL.

Examinations
Finance
General Purposes
Library and Museum
Membership
Papers

SPECIAL COMMITTEES.

Benevolent Fund
Earthing to Water Mains (Joint)
E.H.T. Conference, Paris, British National Committee
Electrical Engineers' Ball
Electrical Interference with Broadcasting
Electricity (Supply) Regulations
Faraday Medal and Honorary Membership Advisory
Informal Meetings
International Relations
Local Centres
Meter and Instrument Section
Model General Conditions
Overhead Lines
Overseas Activities
Patent Law
Scholarships
Science Abstracts
Ship Electrical Equipment Regulations
Wireless Section
Wiring Regulations

Technical Committees.

Electrical Plant and Machinery, including Marine Applications
Electricity in Mines
Electro-Chemistry and Electro-Metallurgy
Industrial, Agricultural and Domestic Applications, including Illumination and Tariffs
Power Stations and their Equipment
Radiological and Electro-Medical Apparatus
Telegraphs and Telephones
Traction, including Railways
Transmission and Distribution

Overseas Committees.

India (Bombay and Lahore)
New South Wales
Queensland
South Australia
Victoria and Tasmania
Western Australia
New Zealand
Transvaal

BODIES ON WHICH THE INSTITUTION IS REPRESENTED.

Aerodromes Advisory Board
Bristol University
British Cast Iron Research Association
British Electrical and Allied Industries Research Association
British National Illumination Committee of the International Illumination Commission
British Standards Institution
Building Industries National Council (Advisory Committee on Building Acts and Byelaws)
City and Guilds of London Institute
Council for the Preservation of Rural England
Electrical Association for Women
Engineering Joint Council
Imperial College of Science and Technology, Governing Body
Imperial Minerals Resources Conference, Copper Committee
Institute of Metals, Corrosion Research Committee
Institution of Civil Engineers, Engine and Boiler Testing Committee
International Association for Testing Materials
International Electrotechnical Commission, British National Committee
Joint Fuel Committee
Leeds Municipal Technical Library Committee
Loughborough Technical College, Advisory Committee
Metalliferous Mining (Cornwall) School, Governing Body
National Certificates and Diplomas in Electrical Engineering, Joint Committees for
National Committee on Physics (Royal Society)
National Committee on Radio-Telegraphy (Royal Society)
National Physical Laboratory, General Board
National Register of Electrical Installation Contractors
National Smoke Abatement Society
Professional Classes Aid Council
Radio Manufacturers' Association, Committee on Battery Eliminators
Royal Engineer Board
Science Museum, S. Kensington, Advisory Council
Town Planning Institute, Committee on Overhead Transmission Lines
Union of Lancashire and Cheshire Institutes, Panel for Engineering
University College, Nottingham, Electrical Engineering Advisory Committee
War Office Mechanization Board
Women's Engineering Society
World Power Conference, British National Committee

THE INSTITUTION OF ELECTRICAL ENGINEERS.

REVENUE ACCOUNT FOR THE YEAR ENDED 31st DECEMBER, 1933.

Dr. EXPENDITURE.

Year ended 31 Dec., 1932.* £ s. d.		£ s. d.	£ s. d.
	To MANAGEMENT:—		
	Salaries and Wages	14,365 2 3	
	Staff Provident Scheme	1,683 9 4	
	National Insurance	104 4 11	
	Audit Fee	73 10 0	
	Printing	932 1 4	
	Stationery and Office Requisites	648 15 7	
	Addressing Machine Requisites	31 3 5	
	Postage of Correspondence and Notices	850 19 7	
	Telephone	110 18 0	
17,841 5 5	Travelling Expenses	513 2 2	19,313 6 7
	„ INSTITUTION BUILDING:—		
	Ground Rent	2,201 0 0	
	Rates	2,376 10 7	
	Heating	274 17 2	
	Lighting and Power	520 1 10	
	Insurance	193 7 6	
	Transferred to Repairs Suspense Account	1,000 0 0	
	Household Requisites and Cleaning	589 18 7	
	Valuation Fees and Advertising	26 8 9	
		7,182 4 5	
2,614 17 8	*Less* Rents from Tenants (after allowances for repairs)	3,151 4 1	4,031 0 4
204 19 11	„ FURNITURE AND FITTINGS (Repairs and Renewals)		618 9 4
	„ JOURNAL:—		
	Printing	5,682 2 3	
	Postage	2,246 2 6	
	Wrappers and Envelopes	362 19 11	
		8,291 4 8	
6,216 14 5	*Less* Sales and Advertisements	3,431 0 5	4,860 4 3
91 0 6	„ PROCEEDINGS OF THE WIRELESS SECTION (Printing, Postage, etc.: *less* Sales)		57 4 4
640 6 3	„ STUDENTS' QUARTERLY JOURNAL (Editing, Printing, Postage, etc.: *less* Sales)		662 10 7
127 6 4	„ LENDING LIBRARY (Books, Printing, Postage, etc.)		151 10 6
	„ SCIENCE ABSTRACTS:—		
	Abstracting, Editing, Printing, Postage, etc.	5,629 11 8	
485 7 10	*Less* Subscriptions, Sales and Advertisements	5,089 14 9	539 16 11
	Carried Forward		£30,234 2 10

INCOME. Cr.

Year ended 31 Dec., 1932.* £ s. d.		£ s. d.	£ s. d.
38,987 1 5	By SUBSCRIPTIONS		38,132 4 6
845 11 0	„ ENTRANCE FEES AND VELLUM DIPLOMA FEES		962 17 0
5,726 7 11	„ DIVIDENDS AND INTEREST		5,540 11 11
158 18 11	„ SALES OF "MODEL GENERAL CONDITIONS"		80 13 9
42 10 4	„ SALES OF "WIRING REGULATIONS"		19 16 10
4 0 7	„ SALES OF "SHIP WIRING REGULATIONS"		8 15 11
	„ EXAMINATIONS:—		
	Graduateship Examination (Candidates' Fees and Sale of Papers, *less* Examiners' Fees, Printing, etc.)	508 16 4	
927 1 0	National Certificates and Diplomas (Candidates' and School Authorities' Fees, *less* Assessors' Fees, Stationery, Postage, Travelling Expenses, etc.)	596 18 8	1,105 15 0
	Carried Forward		£45,850 14 11

REVENUE ACCOUNT—*continued.*

Dr. EXPENDITURE—*continued.*

1932*		£ s. d.	£ s. d.
	Brought Forward		30,234 2 10
	To INSTITUTION MEETINGS:—		
	Advance Proofs	231 18 7	
	Reporting	135 9 0	
	Grant to London Students' Section	53 10 10	
	Honorarium to Kelvin Lecturer	25 0 0	
	Refreshments, Assistance, etc.	373 3 2	
	Travelling Expenses of Authors of Papers	58 5 10	
	Overseas Meetings	69 2 8	
1,069 9 3			946 10 1
	,, LOCAL CENTRES:—		
	Money Grants (including Travelling Expenses of Authors of Papers)	3,416 2 6	
	Travelling Expenses	652 15 8	
	Faraday Lectures	463 11 11	
	Students' Lectures	109 16 10	
4,832 15 5			4,642 6 11
236 5 1	,, PREMIUMS FOR PAPERS		255 6 6
1,116 1 5	,, SCHOLARSHIPS		1,256 0 6
	,, SPECIAL GRANTS:—		
	British Standards Institution	1,000 0 0	
	Electrical Research Association	1,000 0 0	
	National Illumination Committee	32 0 0	
	Radio-Telegraphic Investigations of the Ionosphere	250 0 0	
	Paris Conference on Extra High Tension Systems	14 5 3	
	International Commission on Interference	17 5 8	
2,214 14 6			2,313 10 11
83 11 6	,, ANNUAL DINNER		97 18 0
575 1 3	,, CONVERSAZIONE		607 11 11
89 6 10	,, LEGAL EXPENSES		51 19 4
106 15 5	,, MISCELLANEOUS EXPENSES		169 19 3
38,650 19 0			40,575 6 3
277 12 2	,, AMOUNT TRANSFERRED TO SINKING FUND (Premiums for Redemption of Cost of Building and Lease)	277 12 2	
7,827 17 8	,, **Balance carried to Balance Sheet**	4,997 16 6	
8,105 9 10			5,275 8 8
46,756 8 10			£45,850 14 11

INCOME—*continued.* **Cr.**

1932*		£ s. d.
	Brought Forward	45,850 14 11
46,756 8 10		£45,850 14 11

* These columns do not add up to the totals of Income and Expenditure shown, as some of the items in the Accounts for 1932 did not occur in 1933.

BALANCE SHEET, 31st DECEMBER, 1933.

Dr. LIABILITIES.

	£ s. d.	£ s. d.
To Uninvested Balances of Trust Funds		330 12 4
,, Sundry Creditors		6,791 18 2
,, Subscriptions received in advance		364 5 11
,, Repairs Suspense Account:—		
Balance at 1st January, 1933	5,468 14 11	
Amount set aside in 1933	1,000 0 0	
	6,468 14 11	
Less Expenditure on Repairs in 1933	3,058 18 7	
		3,409 16 4
Carried Forward		£10,896 12 9

ASSETS. **Cr.**

	£ s. d.	£ s. d.
By Institution Building and Lease:—		
Cost	73,028 6 10	
Less Reserve for Depreciation, being Surrender Values of Sinking Fund Policies	8,762 9 0	
		64,265 17 10
,, Sinking Fund (Surrender Values of Policies for Redemption of Cost of Building and Lease)		8,762 9 0
,, Library (exclusive of the Ronalds Library and Faraday Papers, which are held in trust):—		
As per last Balance Sheet	1,773 16 2	
Additions in 1933	265 14 10	
	2,039 11 0	
Less Depreciation (10 %)	203 19 1	
		1,835 11 11
,, Thompson Memorial Library (Contribution towards purchase)		1,000 0 0
,, Furniture, Fittings, and Apparatus:—		
As per last Balance Sheet	4,120 9 9	
Less Depreciation (5 %)	206 0 6	
		3,914 9 3
,, Sundry Debtors		2,297 1 2
,, Insurance Premiums and Sundry Payments in Advance		425 0 8
,, Stock of Paper, Etc., for Publications		753 0 5
,, Investments (at cost):—		
£2,600 Natal Zululand Railways 3 % Debenture Stock	2,270 12 0	
£1,500 London, Midland and Scottish Railway 4 % Preference Stock	1,513 10 4	
£2,000 Assam Bengal Railways 3 % Stock (1931 or after)	1,548 0 6	
£750 Western Australia 4 % Stock (1942–62)	730 8 3	
£750 Union of South Africa 4 % Stock (1943–63)	742 12 0	
£750 Madras and Southern Mahratta Railway 4 % Debenture Stock (1938)	738 15 6	
Carried Forward	£7,543 18 7	£83,253 10 3

BALANCE SHEET—*continued.*

Dr. LIABILITIES—*continued.*

		£ s. d.	£ s. d.
Brought Forward			.. 10,896 12 9
To Surplus of Assets over Liabilities:—			
Balance at 1st January, 1933:—		189,814 1 2	
Excess of Income over Expenditure for 1933 brought forward from Revenue Account		4,997 16 6	
		194,811 17 8	
Less Depreciation:—			
Library (*per contra*) ..	£203 19 1		
Furniture, Fittings, and Apparatus (*per contra*)	206 0 6		
		409 19 7	194,401 18 1
			£205,298 10 10

P. ROSLING,
Honorary Treasurer.

P. F. ROWELL,
Secretary.

ASSETS—*continued.* **Cr.**

	£ s. d.	£ s. d.
Brought Forward	..	.. 83,253 10 3
By Investments (at cost)—*contd.*		
Brought forward	7,543 18 7	
£35 East Indian Railway "B" Annuity (1953) ..	791 5 4	
£1,500 South Australia 4 % Stock (1940–60) ..	1,494 10 6	
£6,450 3½ % War Stock	6,306 9 0	
£19,375 4 % Funding Loan (1960–90)	15,500 0 0	
£8,700 3½ % Conversion Stock (1961 or after) ..	6,651 3 3	
£11,970 11s. 4 % Consolidated Stock	10,291 6 6	
£1,000 London, Midland and Scottish Railway 5 % Preference Stock (1955)	1,020 4 6	
£5,000 North Metropolitan Power Station 5 % Guaranteed Debenture Stock (1957)	4,988 11 0	
£2,000 London, Midland and Scottish Railway 5 % Redeemable Debenture Stock (1952)	1,982 5 9	
£2,300 East Indian Railway 4½ % Irredeemable Debenture Stock	2,019 13 0	
£5,000 Commonwealth of Australia 5 % Stock (1945–75)	4,964 17 6	
£2,000 Tynemouth Corporation 5 % Stock (1947–57)	2,025 4 0	
£2,500 Stoke-on-Trent Corporation 5 % Stock (1948–68)	2,550 6 0	
£3,500 East Indian Railway 3½ % Debenture Stock (1937)	2,475 15 6	
£5,000 Brighton Corporation 4¾ % Stock (1945–75)	5,050 8 0	
£2,000 New South Wales 5¼ % Stock (1947–57) ..	2,013 19 0	
£2,600 Kenya Government 4½ % Stock (1950) ..	2,483 4 0	
£3,000 Southern Railway 4 % Debenture Stock ..	2,520 5 0	
£2,500 India 4½ % Stock (1958–68)	2,329 17 9	
£2,500 Corporation of London 4½ % Debenture Stock (1940–85)	2,462 14 0	
£3,000 Birmingham Corporation 4½ % Stock (1948–68)	2,906 11 0	
£3,000 London County 4½ % Stock (1945–85) ..	2,936 11 0	
£1,000 Bootle Corporation 4¾ % Stock (1949–59)	967 12 0	
£10,000 5 % Conversion Stock (1944–64)	9,888 5 10	
£2,000 Southampton Corporation 5 % Stock (1947–67)	2,027 14 0	
£2,333 London Passenger Transport Board 4½ % "A" Stock (1985–2023)	2,110 5 0	
£2,000 Agricultural Mortgage Corporation 5 % Debenture Stock (1959–89)	2,080 11 0	
£2,400 Ayr County Council 5 % "A" Stock (1947–57)	2,484 4 0	
£2,400 Union of South Africa 5 % Stock (1950–70)	2,436 4 0	
£1,000 Nyasaland Government 4½ % Guaranteed Stock (1952–72)	1,142 13 0	
(*Market value 31st December*, 1933, £136,445 13*s.* 2*d.*)		116,446 9 0
,, Cash in Hands of Local Centres on 30 Sept., 1933 ..	..	1,252 15 3
,, Cash:—		
At Bank	161 0 9	
At Banks in Australia and New Zealand	4,057 10 4	
In hands of Secretary	127 5 3	
		4,345 16 4
		£205,298 10 10

We beg to report that we have audited the Balance Sheet of The Institution of Electrical Engineers, dated 31st December, 1933, and above set forth, together with the annexed Statements of Account. We have obtained all the information and explanations we have required. In our opinion the Statements are correct and the Balance Sheet is properly drawn up so as to exhibit a true and correct view of the state of the Institution's affairs according to the best of our information and the explanations given to us and as shown by the books of the Institution.

10*th April*, 1934.

ALLEN, ATTFIELD & CO., *Auditors*,
Chartered Accountants,
24, Martin Lane, Cannon Street, E.C. 4.

Dr. SALOMONS SCHOLARSHIP TRUST FUND (Capital). Cr.

	£ s. d.		£ s. d.
To Amount (as per last Account)	2,155 14 10	By Investments (at cost):—	
		£1,528 5s. 1d. New South Wales 5 % Stock (1935–55)	1,585 1 4
		£500 Cape of Good Hope 3½ % Stock (1929–49)	570 13 6
	£2,155 14 10		£2,155 14 10

Dr. SALOMONS SCHOLARSHIP TRUST FUND (Income). Cr.

	£ s. d.		£ s. d.
To Amount paid to Scholars in 1933	50 0 0	By Balance (as per last Account)	12 13 3
,, Balance carried to Balance Sheet*	56 11 5	,, Dividends received in 1933	93 18 2
	£106 11 5		£106 11 5

Dr. DAVID HUGHES SCHOLARSHIP TRUST FUND (Capital). Cr.

	£ s. d.		£ s. d.
To Amount (as per last Account)	2,000 0 0	By Investment (at cost):—	
		£2,045 Metropolitan Water Board (Staines Reservoirs) 3 % Guaranteed Debenture Stock (1922 or after)	1,998 15 0
		,, Balance carried to Balance Sheet*	1 5 0
	£2,000 0 0		£2,000 0 0

Dr. DAVID HUGHES SCHOLARSHIP TRUST FUND (Income). Cr.

	£ s. d.		£ s. d.
To Amount paid to Scholars in 1933	100 0 0	By Dividends received in 1933	61 7 0
		,, Interest received in 1933	0 0 6
		,, Contribution from Institution	38 12 6
	£100 0 0		£100 0 0

Dr. PAUL SCHOLARSHIP FUND (Capital). Cr.

	£ s. d.		£ s. d.
To Amount (as per last Account)	1,000 0 0	By Investments (at cost):—	
		£625 4 % Funding Loan (1960–90)	500 0 0
		£518 3s. 8d. Central Electricity Board 5 % Debenture Stock (1950–70)	500 0 0
	£1,000 0 0		£1,000 0 0

Dr. PAUL SCHOLARSHIP FUND (Income). Cr.

	£ s. d.		£ s. d.
To Amount paid to Scholars in 1933	37 10 0	By Balance (as per last Account)	7 2 4
,, Balance carried to Balance Sheet*	20 10 6	,, Dividends received in 1933	50 18 2
	£58 0 6		£58 0 6

Dr. WILDE BENEVOLENT TRUST FUND (Capital). Cr.

	£ s. d.		£ s. d.
To Amount (as per last Account)	3,049 16 2	By Investments (at cost):—	
		£1,308 London and North Eastern Railway 4 % First Guaranteed Stock	1,744 3 11
		£100 London County 3½ % Consolidated Stock (1929 or after)	101 8 6
		£250 New South Wales 4 % Stock (1942–62)	251 6 0
		£500 3½ % War Stock	501 9 3
		£381 15s. 1d. 4 % Funding Loan (1960–90)	300 0 0
		£200 3½ % Conversion Stock (1961 or after)	151 8 6
	£3,049 16 2		£3,049 16 2

Dr. WILDE BENEVOLENT TRUST FUND (Income). Cr.

	£ s. d.		£ s. d.
To Grants made in 1933	211 1 11	By Balance (as per last Account)	220 19 6
,, Balance carried to Balance Sheet*	116 0 7	,, Dividends received in 1933	105 11 8
		,, Interest do. do.	11 4
	£327 2 6		£327 2 6

* Included in the total of £330 12s. 4d. shown on the Liabilities side of the Balance Sheet.

Dr. WAR THANKSGIVING EDUCATION AND RESEARCH FUND (No. 1) (Capital). Cr.

	£ s. d.		£ s. d.
To Amount (as per last Account)	1,700 0 0	By Investment (at cost):— £2,000 3½ % War Stock	1,700 0 0
	£1,700 0 0		£1,700 0 0

Dr. WAR THANKSGIVING EDUCATION AND RESEARCH FUND (No. 1) (Income). Cr.

	£ s. d.		£ s. d.
To Grants made in 1933	100 0 0	By Balance (as per last Account)	90 0 0
,, Balance carried to Balance Sheet*	60 0 0	,, Dividends received in 1933	70 0 0
	£160 0 0		£160 0 0

Dr. PAGE PRIZE FUND (Capital). Cr.

	£ s. d.		£ s. d.
To Amount (as per last Account)	100 19 5	By Investments (at cost):—	
		£50 3½ % War Stock	50 19 5
		£51 16s. 4d. Central Electricity Board 5 % Debenture Stock (1950–70)	50 0 0
	£100 19 5		£100 19 5

Dr. PAGE PRIZE FUND (Income). Cr.

	£ s. d.		£ s. d.
To Cost of Prize awarded in 1933	4 7 10	By Balance (as per last Account)	2 5 0
,, Balance carried to Balance Sheet* ..	2 4 0	,, Dividends received in 1933	4 6 10
	£6 11 10		£6 11 10

Dr. THORROWGOOD SCHOLARSHIP TRUST FUND (Capital). Cr.

	£ s. d.		£ s. d.
To Amount (as per last Account)	1,000 0 0	By Investment (at cost):— £1,005 Agricultural Mortgage Corporation 5 % Debenture Stock (1959–89)	1,000 0 0
	£1,000 0 0		£1,000 0 0

Dr. THORROWGOOD SCHOLARSHIP TRUST FUND (Income). Cr.

	£ s. d.		£ s. d.
To Amount paid to Scholars in 1933	50 0 0	By Balance (as per last Account)	56 14 5
,, Balance carried to Balance Sheet* ..	56 19 5	,, Dividends received in 1933	50 5 0
	£106 19 5		£106 19 5

Dr. SWAN MEMORIAL SCHOLARSHIP FUND (Capital). Cr.

	£ s. d.		£ s. d.
To Amount (as per last Account) ..	2,968 12 4	By Investments (at cost):—	
		£1,000 Sunderland Corporation 5 % Stock (1946–56)	1,116 13 0
		£640 Sunderland Corporation 5 % Stock (1950–60)	728 8 0
		£1,135 17s. 9d. 3½ % Conversion Stock (1961 or after)	1,123 11 4
	£2,968 12 4		£2,968 12 4

Dr. SWAN MEMORIAL SCHOLARSHIP FUND (Income). Cr.

	£ s. d.		£ s. d.
To Account paid to Scholars in 1933	120 0 0	By Balance (as per last Account)	15 8 1
,, Balance carried to Balance Sheet* ..	17 1 5	,, Dividends received in 1933	121 13 4
	£137 1 5		£137 1 5

* Included in the total of £330 12s. 4d. shown on the Liabilities side of the Balance Sheet.

THE BENEVOLENT FUND OF THE INSTITUTION OF ELECTRICAL ENGINEERS.

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR 1933.

Dr. EXPENDITURE.

Year ended 31 Dec., 1932. £ s. d.			£ s. d.
	To Grants	£2,599 15 3	
	Less Previous Grants refunded	1 5 0	
1,952 8 9			2,598 10 3
29 15 4	,, Printing, Stationery, Bank Charges, Postages, etc.		22 11 11
1,313 2 9	,, Unexpended Balance carried to Balance Sheet		1,331 16 1
£3,295 6 10			£3,952 18 3

INCOME. Cr.

		£ s. d.	Year ended 31 Dec., 1932. £ s. d.
By Dividends and Interest		873 8 4	
,, London Electrical Engineers' Ball:—			
Profit on 1933 Ball	£224 3 4		
Balance from previous Balls ..	219 8 4		
		443 11 8	
,, Mersey and North Wales (Liverpool) Centre Golf Tournament		63 17 6	
,, North-Western Centre Golf Tournament		50 0 0	
,, South Midland Electrical Engineers' Ball.. ..		52 10 0	
,, North Midland Centre Electrical Engineers' Ball..		35 0 0	
,, British Electrical Development Association, Newcastle-on-Tyne Carnival		35 0 0	
,, Gift from the Nizam of Hyderabad		100 0 0	
,, Other donations of £5 and over		369 17 0	
,, Donations under £5		1,032 2 3	
,, Annual Subscriptions		897 11 6	
		£3,952 18 3	£3,295 6 10

BALANCE SHEET, 31st DECEMBER, 1933.

Dr. LIABILITIES.

		£ s. d.
To Capital Account:—		
As per last Balance Sheet	£17,811 17 2	
Amount transferred from Income Account in 1933	2,479 18 6	
		20,291 15 8
,, Income and Expenditure Account:—		
As per last Balance Sheet	£3,962 17 4	
Unexpended Balance in 1933	1,331 16 1	
	5,294 13 5	
Less Amount transferred to Capital Account in 1933	2,479 18 6	
		2,814 14 11
,, Grants authorized but not yet disbursed		26 0 0
,, Sundry Creditors		8 15 8
,, Subscriptions and Donations received in advance		27 4 0
		£23,168 10 3

ASSETS. **Cr.**

		£ s. d.
By Investments (Capital), at cost:—		
£961 7s. 7d. Cape of Good Hope 3 % Stock (1933–43) ..		950 0 0
£593 1s. 7d. New South Wales 3 % Stock (1935)		600 0 0
£420 London and North Eastern Railway 4 % First Preference Stock		503 18 3
£450 London, Midland and Scottish Railway 4 % Debenture Stock		551 0 9
£750 East Indian Railway $3\frac{1}{2}$ % Debenture Stock		737 18 0
£300 London, Midland and Scottish Railway 4 % Guaranteed Stock		333 11 6
£500 New Zealand $3\frac{1}{2}$ % Stock (1940)		486 18 6
£500 Canada $3\frac{1}{2}$ % Stock (1930–50)		478 16 0
£5,800 $3\frac{1}{2}$ % War Stock		5,783 6 1
£350 New South Wales 4 % Stock (1942–62)		336 18 6
£2,580 4 % Funding Stock (1960–90)		2,123 15 6
£3,295 $3\frac{1}{2}$ % Conversion Stock (1961)		2,512 11 10
£450 Commonwealth of Australia 5 % Stock (1945–75) ..		438 16 0
£450 Tynemouth Corporation 5 % Stock (1947–57) ..		457 7 3
£950 Agricultural Mortgage Corporation 5 % Debenture Stock (1959–89)		988 5 6
£1,000 Southern Railway 5 % Redeemable Guaranteed Preference Stock (1957)		1,028 7 0
£1,000 Southern Railway 5 % Guaranteed Preference Stock		1,000 3 0
£1,000 Hastings Corporation 5 % Stock (1947–67)		980 2 0
		£20,291 15 8
(*Market value 31st December*, 1933, *£22,314 1s. 11d.*)		
,, Investments (Income) at cost:—		
£800 London Passenger Transport Board 5 % "A" Stock (1985–2023)	808 2 6	
£700 Ayr County Council 5 % Stock (1947–57)	733 7 0	
£1,000 Commonwealth of Australia 4 % Stock (1955–70)	1,012 13 0	
		2,554 2 6
(*Market value 31st December*, 1933, *£2,854 0s. 0d.*)		
,, Sundry Debtors		27 7 6
,, Cash:—		
At Bank	282 3 11	
In hand	13 0 8	
		295 4 7
		£23,168 10 3

I have audited the above Balance Sheet and Income and Expenditure Account with the Books and Vouchers and certify them to be correct, and have verified the Investments with Certificates from Banks.

* 10*th April*, 1934.

JAS. ATTFIELD, F.C.A.
Honorary Auditor.

PROCEEDINGS OF THE INSTITUTION.

861st ORDINARY MEETING, 4th JANUARY, 1934.

Mr. P. V. Hunter, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 21st December, 1933, were taken as read and were confirmed and signed.

The following list of donors to the Library was taken as read, and the thanks of the meeting were accorded to them:—Air Ministry; American Institute of Electrical Engineers; American Society of Mechanical Engineers; American Telephone and Telegraph Co; The Astronomer Royal; Australian Radio Research Board; Librairie J. B. Baillière et fils; Messrs. Ernest Benn, Ltd.; D. J. Bolton, M.Sc.; E. Booth, M.C., B.Sc.; Sir W. H. Bragg, O.M., K.B.E., D.Sc., F.R.S.; British Association for the Advancement of Science; British Electrical and Allied Industries Research Association; British Engine, Boiler, and Electrical Insurance Co., Ltd.; British Radio Institute; British Standards Institution; C. A. C. Brown, B.Sc.; Messrs. Cambridge University Press; Canadian Department of Mines; Central Electricity Board; H. J. B. Chapple, B.Sc.; The Chief Inspector of Factories and Workshops; H. W. Clothier; Librairie Armand Colin; A. F. Collins, F.R.A.S.; Congrès International d'Électricité, 1932; F. W. Crawter; H. J. Denham, M.A., D.Sc.; Department of Scientific and Industrial Research; Dienst voor Watertracht en Electriciteit in Nederlandsch-Indie; W. H. Eccles, D.Sc.; Electric Supply Authority Engineers' Association of New Zealand; Electrical Association of Japan; "Electrical Trading and Electricity"; The Electricity Commissioners; Electricity Supply Commission, S.A.; Elektrotechnicky svaz Ceskoslovensky; A. A. England; Messrs. Ferranti, Ltd.; K. Hedges; W. L. Horwood, B.Sc.; L. E. C. Hughes, Ph.D.; Hull Association of Engineers; Messrs. Iliffe and Sons, Ltd.; Incorporated Municipal Electrical Association; India Posts and Telegraphs Department; Institute of Marine Engineers; Institution of Engineers-in-Charge; Institution of Gas Engineers; International Electrotechnical Commission; International Standard Electric Corporation; W. H. Jones, B.Sc.; R. Judson; P. Kemp, M.Sc.; Prof. A. E. Kennelly, D.Sc.; Kinematograph Publications, Ltd.; Messrs. W. King, Ltd.; G. Kron; Sir Oliver Lodge, D.Sc., F.R.S.; Librairie de l'Enseignement Technique; London and Home Counties Joint Electricity Authority; Messrs. McGraw-Hill Publishing Co., Ltd.; W. A. McKay; E. Mallett, D.Sc.(Eng.); F. J. Mars; J. W. Meares, C.I.E.; Mines Department; E. Molloy; S. G. Monk, B.Sc.; National Electrical Manufacturers' Association, N.Y.; National Illumination Committee of Great Britain; New Zealand Hydro-Electric Development; Messrs. J. Nisbet and Co., Ltd.; W. Norburn; Norway Watercourse and Electricity Service; P. O. Pedersen; Physical Society; R. F. R. Pierce; Messrs. Sir Isaac Pitman and Sons, Ltd.; Punjab Public Works Department; E. T. A. Rapson; H. Rees; Rubber Growers' Association, Inc.; A. R. Rubin; Science Museum; J. F. Shipley; Messrs. Siemens Brothers and Co., Ltd.; S. Parker Smith, D.Sc.; Smithsonian Institution; N. Stoyko; Tasmanian Hydro-Electric Commission; F. H. Taylor; W. A. Tookey; Transit Journal, N.Y.; R. N. Vyvyan; A. F. Webber, B.Sc.; H. J. W. Wildbore; G. Windred; A. T. Witts; H. Young.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

The President announced that, during the month of December, 48 donations and subscriptions to the Benevolent Fund had been received, amounting to £22. A vote of thanks was accorded to the donors.

A paper by Mr. J. L. Miller, Ph.D., B.Eng., Associate Member, entitled "The Influence of Certain Transmission-Line Associated Apparatus on Travelling Waves" (see vol. 74, page 473), and a paper by Messrs. J. L. Miller, Ph.D., B.Eng., Associate Member, and J. E. L. Robinson, M.Sc., Graduate, entitled "The Design and Operation of a High-Speed Cathode-Ray Oscillograph" (see vol. 74, page 511), were read and discussed.

The meeting terminated at 7.45 p.m. with a vote of thanks to the authors, which was moved by the President and carried with acclamation.

862nd ORDINARY MEETING, 18th JANUARY, 1934.

Mr. P. V. Hunter, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 4th January, 1934, were taken as read and were confirmed and signed.

Messrs. S. H. Richards and J. E. Taylor were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the President reported that the members whose names appeared on the lists (see vol. 74, page 280), had been duly elected and transferred.

The President then called on Viscount Falmouth to present to the Institution a portrait of the late Sir Charles Parsons by Sir William Orpen.

Viscount Falmouth: The Institution has in this Lecture Theatre a number of portraits of men who were

prominent in the development of the electrical industry, and I am confident that in future years these portraits will be of the greatest interest to engineers. Of the names of those men who built up our industry, one of the most honoured is that of Sir Charles Parsons. He was an Honorary Member of our Institution, and also a Faraday Medallist. In the early 'eighties he took a prominent part in the development of the high-speed dynamo and, subsequently, in that of the alternator; and towards the close of his busy life, throughout which he never lost interest in the electrical side of the development of the turbine, he was actively engaged on problems connected with the high-voltage alternator. It is not, however, simply as an electrical engineer that the name of Parsons will go down to posterity; he will always be regarded as the man to whom the world is indebted for the steam turbine. His inventions, and the improvements which he made in what was at that time merely a scientific toy, were of such paramount importance that what was once a toy has become one of the greatest engines for the benefit of mankind. The lives of Watt and Parsons contain many similar features. Both men had that divine gift of genius which enabled them to see clearly what other men were dimly groping for. Both men had wonderful courage and great patience, and overcame tremendous technical difficulties in perfecting their inventions. Both men, again, had to meet with opposition from unexpected sources; and, finally, both men lived to see the triumph of their ideas. I think it was in 1884 that Parsons built the original turbine; but it was not until 1900 that the 1 000-kW Elberfeld machines were started up and that engineers had confidence in the steam turbine. They then realized what Parsons had realized all along, namely that in the steam turbine man had a prime mover of far greater efficiency than any existing steam engine, one capable of being developed to any size and also possessing considerable other technical advantages. From the day that the Elberfeld machines were started up, the steam turbine never looked back; and wherever, throughout the world, there is a large power station other than those run by water-power, there it is certain that a steam turbine is in operation. This is a wonderful development in so short a time, and an amazing tribute to the genius of one man. Those who knew Parsons were always impressed by his extraordinary modesty, and I have sometimes wondered if he realized how exceptional were the gifts with which he was endowed and of which he made such splendid use. To the last there was much of the eternal boy in him, a great enthusiasm for new ideas, for making experiments of all kinds large and small, and if they ended in a bang or a flare-up, so much the happier was he. It was, I think, this characteristic more than any other that made him such a delightful companion to all who knew him well. I will not detain you any longer. Parsons and his works speak for themselves, their effects are visible to us on every side, and I will ask the President to accept this picture of a great man to add to those already belonging to the Institution.

The President: It gives me great pleasure to accept this portrait on behalf of the Council and the members of the Institution. I think we all shall agree that no more appropriate portrait could be hung on the walls of this Institution than that of the late Sir Charles Parsons. In addition to being an Honorary Member and a Faraday Medallist, he served for a time as Vice-President; and we must also remember that he presented us with the portrait of Swan which hangs in this Lecture Theatre. I therefore feel that I need add nothing to what Lord Falmouth has said, and with very much pleasure I accept this portrait on behalf of the Institution.

A paper by Mr. H. Rissik, B.Sc.(Eng.), Graduate, entitled "Some Aspects of the Electrical Transmission of Power by means of Direct Current at Very High Voltages" (see vol. 75, page 1), was read and discussed.

The meeting terminated at 7.55 p.m. with a vote of thanks to the author, which was moved by the President and carried with acclamation.

863RD ORDINARY MEETING, 1ST FEBRUARY, 1934.

Mr. P. V. Hunter, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 18th January, 1934, were taken as read and were confirmed and signed.

The President announced that the Council had elected Dr. R. Thury, of Geneva, an Honorary Member of the Institution, and that the twelfth award of the Faraday Medal had been made to Sir Frank E. Smith, K.C.B., C.B.E., D.Sc., LL.D., F.R.S.

He also announced that, during the month of January, 2 771 donations and subscriptions to the Benevolent Fund had been received, amounting to £1 335. A vote of thanks was accorded to the donors.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

A paper by Mr. B. S. Cohen, O.B.E., Member, entitled "Research in the British Post Office" (see vol. 75, page 133), was read and discussed.

The meeting terminated at 7.45 p.m. with a vote of thanks to the author, which was moved by the President and carried with acclamation.

864TH ORDINARY MEETING, 15TH FEBRUARY, 1934.

Mr. P. V. Hunter, C.B.E., President, first took the chair at 6 p.m., and, owing to his having subsequently to leave the meeting in order to fulfil another engagement, the chair was later taken by **Mr. J. M. Kennedy,** Vice-President.

The minutes of the Ordinary Meeting held on the

1st February, 1934, were taken as read and were confirmed and signed.

A paper by Mr. F. Ohlmuller, Dipl.Ing., entitled "The Influence of the Benson Boiler on the Development of Power Stations" (see vol. 75, page 161), was read and discussed. The meeting terminated at 8 p.m. with a vote of thanks to the author, which was moved by the chairman and carried with acclamation.

865TH ORDINARY MEETING, 22ND FEBRUARY, 1934.

Mr. P. V. Hunter, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 15th February, 1934, were taken as read and were confirmed and signed.

Messrs. W. L. Beck and R. A. Smith were appointed scrutineers of the ballot for the election and transfer of members and, at the end of the meeting, it was reported that the members whose names appeared on the lists (see vol. 74, page 375) had been duly elected and transferred.

A paper by Mr. L. G. H. Sarsfield, M.Sc.(Eng.), Member, entitled "Safety Measures in X-Ray Work, including High-Voltage Flexible Cables" (see vol. 75, page 253), was read and discussed.

The meeting terminated at 7.55 p.m. with a vote of thanks to the author, which was moved by the President and carried with acclamation.

866TH ORDINARY MEETING, 8TH MARCH, 1934.

Mr. P. V. Hunter, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 22nd February, 1934, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

The President announced that, during the month of February, 540 donations and subscriptions to the Benevolent Fund had been received, amounting to £312. A vote of thanks was accorded to the donors.

A paper by Messrs. B. A. G. Churcher, Member, A. J. King, B.Sc.Tech., Associate Member, and H. Davies, M.Eng., Graduate, entitled "The Measurement of Noise, with special reference to Engineering Noise Problems" (see vol. 75, page 401), was read and discussed.

The meeting terminated at 8 p.m. with a vote of thanks to the authors, which was moved by the President and carried with acclamation.

867TH ORDINARY MEETING, 15TH MARCH, 1934.

Mr. P. V. Hunter, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 8th March, 1934, were taken as read and were confirmed and signed.

Mr. Clifford C. Paterson, O.B.E., then delivered the Tenth Faraday Lecture, entitled "The Electrical Engineer and the Free Electron" (see vol. 75, page 447). The meeting terminated at 7.15 p.m. with a vote of thanks to the lecturer, which was moved by the President and carried with acclamation.

868TH ORDINARY MEETING, 22ND MARCH, 1934.

Mr. P. V. Hunter, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 15th March, 1934, were taken as read and were confirmed and signed.

Messrs. H. A. Pirie and H. B. Rantzen were appointed scrutineers of the ballot for the election and transfer of members and, at the end of the meeting, the President reported that the members whose names appeared on the list (see vol. 74, page 471) had been duly elected and transferred.

A paper by Mr. T. S. Skillman, M.A., Associate Member, entitled "Developments in Long-Distance Telephone Switching" (see vol. 75, page 545), was read and discussed.

The meeting terminated at 7.50 p.m. with a vote of thanks to the author, which was moved by the President and carried with acclamation.

869TH ORDINARY MEETING, 12TH APRIL, 1934.

Mr. P. V. Hunter, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 22nd March, 1934, were taken as read and were confirmed and signed.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

The President announced that, during the month of March, 392 donations and subscriptions to the Benevolent Fund had been received, amounting to £169. A vote of thanks was accorded to the donors.

A paper by Mr. W. G. Thompson, Ph.D., B.Sc., Graduate, entitled "The Application of a Gas-Cooled Arc to Current Conversion, with special reference to the Marx-Type Rectifier" (see vol. 75, page 603), was read and discussed.

The meeting terminated at 8.5 p.m. with a vote of thanks to the author, which was moved by the President and carried with acclamation.

870TH ORDINARY MEETING, 26TH APRIL, 1934.

Mr. P. V. Hunter, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 12th April, 1934, were taken as read and were confirmed and signed.

Messrs. T. Mitchell and E. Kaempf were appointed scrutineers of the ballot for the election and transfer of members and, at the end of the meeting, the President reported that the members whose names appeared on the list (see vol. 74, page 603) had been duly elected and transferred.

A list of candidates for election and transfer, approved by the Council for ballot, was taken as read and was ordered to be suspended in the Hall.

Messrs. F. E. J. Ockenden, W. A. Ritchie, and E. S. Ritter were appointed scrutineers of the ballot for the election of new Members of Council.

The President presented the Faraday Medal for 1933 (twelfth award) to Sir Frank E. Smith, K.C.B., C.B.E., D.Sc., F.R.S.

Professor J. C. McLennan, D.Sc., LL.D., F.R.S., then delivered the Twenty-Fifth Kelvin Lecture, entitled "Electrical Phenomena at Extremely Low Temperatures" (see vol. 75, page 693).

A vote of thanks to the lecturer, proposed by Mr. Clifford C. Paterson, O.B.E., and seconded by Lieut.-Col. K. Edgcumbe, T.D., R.E.T.(Ret.), was carried with acclamation.

The meeting terminated at 7.35 p.m.

871ST ORDINARY MEETING, 3RD MAY, 1934.

Mr. P. V. Hunter, C.B.E., President, took the chair at 6 p.m.

The minutes of the Ordinary Meeting held on the 26th April, 1934, were taken as read and were confirmed and signed.

The President announced that, during the month of April, 253 donations and subscriptions to the Benevolent Fund had been received, amounting to £93. A vote of thanks was accorded to the donors.

A paper by Dr. Ing. M. Schleicher entitled "Modern Practice in Germany and the European Continent with regard to Supervisory Control Systems as applied to Large Interconnected Supply Areas" (see vol. 75, page 710), was read and discussed. The paper was presented on behalf of the author by Mr. J. W. Rissik, B.Sc.(Eng.), Associate Member, and was illustrated by a cinematograph film.

A vote of thanks was accorded to the author for his paper and also to Mr. Rissik for presenting it.

The meeting terminated at 7.30 p.m.

62ND ANNUAL GENERAL MEETING, 10TH MAY, 1934.

Mr. P. V. Hunter, C.B.E., President, took the chair at 6 p.m.

The notice convening the meeting was taken as read.

The minutes of the Ordinary Meeting held on the 3rd May, 1934, were also taken as read and were confirmed and signed.

Messrs. A. N. D. Kerr and L. W. Phillips were appointed scrutineers of the ballot for the election and transfer of members, and, at the end of the meeting, the President reported that the members whose names appeared on the list (see vol. 75, page 131) had been duly elected and transferred.

The Premiums (see vol. 74, page 602, and vol. 75, page 130) which had been awarded by the Council for papers during the session were then announced by the President.

The President next summarized the Annual Report of the Council (see vol. 75, page 807) and moved its adoption, which was seconded by **Mr. H. T. Young.**

Mr. L. W. Phillips: I congratulate the Council particularly on their decision to arrange for speaking films of eminent electrical engineers, and also on the formation of a Transmission Section. In this connection I suggest that the Council consider the formation

of a special Section to discuss papers dealing with the industrial and social changes which are likely to follow the increasing applications of electricity. I should also like to see a closer rapprochement between this Institution and medical institutions in order that discussions may be held on the medical and physiological aspects of electricity. I also wish that the *Journal* could be made of more general interest.

Mr. A. N. D. Kerr: When the Council next revise the Bye-laws I hope that they will bear in mind the inconsistency which exists in regard to membership of the Students' Sections. At present a Student is eligible to remain in the Students' Section until the end of his 28th year, whereas a Graduate can remain in the Section only until he reaches the age of 28. Thus a Student, on attaining the age of 28, forfeits the privileges of membership of a Students' Section if he transfers to the Graduate class.

After the **President** had promised that the points which had been raised would receive careful consideration and had suggested that as the *Journal* reflected very closely the actual aims and constitution of the Institution then if it fell short of what it ought to be it must be to some extent the fault of the members themselves, the resolution in regard to the adoption of the Annual Report was put to the meeting and was carried unanimously.

Mr. P. Rosling (*Hon. Treasurer*): I have pleasure in moving "That the Statement of Accounts and Balance Sheet for the year 1933,* as presented, be received and adopted." The Revenue Account, on the second page of the Accounts, shows a surplus of £4 998, against £7 828 in 1932. The difference of £2 830 is accounted for mainly by two items: first, the reductions in the rates of subscription which came into force in 1933, and secondly, the reduction in the total rents received from tenants as a consequence of the removal of the British Broadcasting Corporation. The whole of the empty portions of the building have, however, since been let, and the rents received will eventually be as high as in former years. The total expenditure for 1933 was £40 575, against £38 651 in 1932, an increase of £1 924. The chief increases were in Management, £1 472; Building, £1 416; Furniture and Fittings (repairs and renewals), £413; Scholarships, £140; and Special Grants, £99. There was reduced expenditure on the *Journal* £1 357; on Meetings, £123; and on Local Centres, £190. The cost of the Building was higher owing to a reduction of £1 374 in the rents received from tenants, after allowances for alterations for new tenants. The increase in Repairs and Renewals of Furniture was due to the extension of the offices on the first floor, and the provision and furnishing of an additional Committee Room. A special grant of £250, which will not recur, was made for radio-telegraphic investigations on the ionosphere. With regard to savings, the *Journal* contained about 1 200 pages in 1933, against 1 500 in 1932, and the cost of Meetings was also less. The saving on Local Centres was chiefly due to the reduction of railway fares included in the travelling expenses. Items of expenditure in 1932 which did not recur in 1933 were South Midland Centre Library (£50) and the cost of a bust of Faraday (£105) presented to the German Museum at Munich. The income for 1933 amounted to £45 851, against £46 756 in 1932, a decrease of £905. The loss due to the reduction of subscriptions was £855, while the rest of the receipts show small increases or decreases. Referring to the Balance Sheet, the total assets are £205 299, and the liabilities £10 897, giving a surplus of assets over liabilities of £194 402. But of that liability of £10 897, about £3 400 is a Suspense Account; it is really a reserve, so that we are actually better off than the figures show by £3 400. The surplus of £194 402 just mentioned compares with £189 814 at the end of 1932, an improvement of £4 588. The larger expenditure on Building repairs is accounted for by the renovation of the parts of the Building formerly occupied by the British Broadcasting Corporation, from whom a sum of £2 375 was received in 1932 for this purpose. With regard to the Assets, the Building and Investments are taken at cost, and the Library and Furniture at cost after writing off depreciation. The investments stand at the cost price of £116 446, and their market value on the 31st December, 1933, was £136 446, which is £20 000 above their cost. A further valuation made on the 27th April of this year shows that they have increased still further in value to £138 629, which is £22 183 above their cost. Institution cash banked in Australia and New Zealand now amounts to £4 058. This is on deposit at 3 per cent. It will be seen from these figures that the Institution continues to enjoy a position of sound financial security. I should like to say that for the two years I have been Honorary Treasurer I have done a certain amount of work for the Institution, but that work has been made very easy by the assistance I have had from Mr. Rowell and the Accounting Staff. The Accounts are prepared in such a way that anyone can be thoroughly satisfied with them. I have searched very carefully to find mistakes, but in two years I have never found one.

* See page 816.

The resolution was seconded by **Mr. F. W. Purse.**

Suggestions were made by two members in regard to (1) the provision of additional seating accommodation in the Lecture Theatre on such occasions as the President's Address and the Kelvin Lecture, and (2) the refreshments provided at the Ordinary Meetings.

The President replied that the suggestions would be carefully considered.

The motion for the adoption of the Accounts was then put to the meeting by the President and was carried unanimously.

The President: I now move "That the best thanks of the Institution be accorded to the following officers for their valuable services during the past year: (*a*) the Hon. Secretaries of the Local Centres; (*b*) the Local Hon. Secretaries abroad; and (*c*) the Hon. Treasurer, Mr. P. Rosling."

The motion was carried with acclamation.

Mr. H. J. H. Tabor then moved "That Messrs. Allen, Attfield and Co. be appointed auditors for the year 1934–35."

The motion was seconded by **Prof. J. T. MacGregor-Morris** and was carried unanimously.

The meeting terminated at 6.50 p.m.

THE BENEVOLENT FUND.

36TH ANNUAL GENERAL MEETING, 10TH MAY, 1934.

Mr. P. V. Hunter, C.B.E., President, took the chair at 5.30 p.m.

The notice convening the meeting was taken as read. The minutes of the 35th Annual General Meeting held on the 11th May, 1933, were also taken as read and were confirmed and signed.

The Report of the Committee of Management (see below) and the Statement of Accounts for the year 1933 (see page 822), were presented and, on the motion of the Chairman, seconded by Mr. P. Rosling, were unanimously adopted.

On the motion of the Chairman it was resolved that Mr. J. Attfield, F.C.A., be appointed Honorary Auditor for the year 1934.

The Chairman reported that, under Rule 15, the Council had appointed the following Committee of Management for the year 1933–34:—

The President (*ex-officio*);

W. McClelland, C.B., O.B.E.
F. W. Purse
P. Rosling
R. H. Schofield
J. W. J. Townley
Johnstone Wright
} representing the Council;

J. F. W. Hooper
A. L. Lunn
W. R. Rawlings
} representing the contributors;

and the Chairmen of the Local Centres in the United Kingdom and Ireland.

On the motion of Mr. H. T. Young, seconded by Mr. Ll. B. Atkinson, the thanks of the meeting were unanimously accorded to the Committee of Management and to the Electrical Engineers' Ball Committee for their services during the past year.

REPORT OF THE COMMITTEE OF MANAGEMENT OF THE BENEVOLENT FUND FOR 1933.

Capital.

The Capital Account stood on the 31st December, 1933, at £20 291 15s. 8d., which is invested. During the year an amount of £2 479 18s. 6d. was transferred to this Account from the Income Account.

Receipts.

The Income for 1933 from dividends, interest, and annual subscriptions, was as follows:—

	£	s.	d.
Dividends and Interest	873	8	4
1 610 Annual Subscriptions	897	11	6
	£1 770	19	10

In addition to the foregoing, the Fund benefited during the year by the following amounts:—

	£	s.	d.
H.H. the Nizam of Hyderabad	100	0	0
Mersey and North Wales (Liverpool) Centre, Golf Tournament	63	17	6
South Midland Electrical Engineers' Ball	52	10	0
North-Western Centre, Golf Tournament	50	0	0
Western Centre and West Wales Sub-Centre	45	9	6
North Midland Centre Electrical Engineers' Ball	35	0	0
British Electrical Development Association (donation from proceeds of carnival at Newcastle-on-Tyne)	35	0	0
"Twenty-Five Club"	26	5	0
Incorporated Municipal Electrical Association	10	10	0
North Midland Centre, collection at Opening Meeting of Session	10	7	0
Proceeds of Golf Competition for "Dennis Trophy" at Bournemouth	6	12	6
National Register of Electrical Installation Contractors	5	5	0
South Midland Students' Section, surplus from Ball	5	0	0
Henley's Telegraph Works Co., Ltd.	25	0	0
General Electric Co., Ltd.	10	10	0
Messrs. Kennedy and Donkin	10	10	0
Messrs. Mavor and Coulson	10	10	0
Messrs. Merz and McLellan	10	10	0
P. Rosling	10	10	0
J. D. Dallas	10	0	0
Sir George Sutton, Bart.	10	0	0
J. D. Butcher	6	17	0
S. R. Mullard	5	16	0
Sir Hugo Hirst, Bart.	5	5	0
L. C. F. Bellamy	5	0	0
"C 2"	5	0	0
J. M. Donaldson	5	0	0
R. G. Kilburne	5	0	0
Marchese G. Marconi	5	0	0
H. E. Morrow	5	0	0
G. H. Nisbett	5	0	0
K. A. Scott Moncrieff	5	0	0
E. A. Short	5	0	0
and 2 837 donations of under £5	1 032	2	3
	£1 638	6	9

The accumulated balance of the Income and Expenditure Account amounted on the 31st December, 1933, to £2 814 14s. 11d., of which £2 554 2s. 6d. was invested and £150 was on deposit with the Institution bankers.

Donors and Subscribers.

Lists of the names of donors and subscribers are issued annually to members of the Institution.

The Committee of Management desire to acknowledge their indebtedness to the donors and subscribers and to intimate that, apart from donations, the Committee will be grateful for annual subscriptions of any amount, as the Committee are anxious that the Capital Account should be steadily augmented so as to strengthen the financial position of the Fund.

Grants.

Applications for assistance were made by or on behalf of 59 persons during 1933, and the Committee, after due consideration, made grants in 53 cases. The figures for 1932 were 49 and 44 respectively.

The total amount of the grants was £2 599 15s. 3d. which compares with £1 956 3s. 7d. for 1932.

Wilde Fund.

The Capital Account stood on the 31st December, 1933, at £3 049 16s. 2d., all of which is invested and brings in an annual income of about £105 12s.

The balance standing to the credit of the Income Account (from which, under the Trust Deed, full Members only can benefit) on the same date was £116 0s. 7d.

Grants amounting to £211 1s. 11d. were made from this Fund during the year.

Electrical Engineers' Ball.

The Annual Electrical Engineers' Ball is now held under the auspices of the Committee of Management. The Ball held on the 17th February, 1933, realized a surplus of £224, which was handed over to the Fund, and the Electrical Engineers' Ball Committee also presented the Fund with the balance of £219 8s. 4d. which they had in hand from previous Balls.

INSTITUTION NOTES.

Parking of Cars.

The Secretary desires to warn the members that the police will not permit the parking of cars in the streets adjacent to the Institution building. Cars are only allowed to remain outside the building for a sufficient length of time (usually not more than 20 minutes) to permit of the setting down and picking up of passengers.

International E.H.T. Conference, Paris.

The probable dates for the next session are the 6th to 15th June, 1935, and the programme will be divided as follows: (*a*) Utilization, interconnection, and protection. (*b*) Power station and substation equipment. (*c*) Construction, insulation, and maintenance of overhead and underground lines.

Any British engineer proposing to present a paper coming within the scope of one of the above headings should notify the Secretary of the Institution forthwith, and subsequently submit the MS. through the Institution for transmission to Paris, thus ensuring the desired co-operation with the British National Committee, which was set up some years ago under the aegis of the Institution.

Elections and Transfers.

At the Ordinary Meeting of the Institution held on the 8th November, 1934, the following elections and transfers were effected:—

Elections.

Associate Members.

Archer, William James, Electrical Lieut., R.N.
Balfre, Xavier Henry.
Barnard, George.
Brace, Harvey Phillips.
Castell, Geoffrey Owen.
Cloran, Michael Dermot.
Dalgleish, James White, B.Sc.
Dane, Henry.

Associate Members—continued.

Davidson, Hugh Samuel.
Dixon, Edmund Joseph C., B.Sc.(Eng.).
Dunderdale, Alston.
Durham, Geoffrey.
Epps, Herbert Fletcher, B.Sc.
Godfrey, George Farrington.
Hahn, Wolfgang.
Herczeg, Akos, Dr.Pol., Dipl.Ing.
Hughes, Henry George, M.Sc.
Ingram, Edward Rendell.
Little, Gilbert Joseph S.
Nicoll, Henry William.
Phear, Howard William, M.A.
Poole, Ralph.
Ross, Daniel.
Sadler, Gilbert Vaughan.
Sprawson, Julius Howard.
Todd, Robert Walker.
Trend, Walter Gristock.
Ure, William, B.Sc.
Walker, Ronald Claude, B.Sc.
Walton, Walter Edward.
Woods, Ronald Arthur, B.Sc.(Eng.).

Associates.

Adams, Hugh Benedict.
Bagshaw, George William.
Gerrard, Tom.
Gibson, Thomas.
Hobbins, Geoffrey Arthur.
Waddington, Basil.

Graduates.

Adcock, Noel Charles.
Appasamy, Chelliah Sulochanam, B.A.
Baker, Alan William, B.A.
Barley, Eric Arthur H.
Barnes, Philip Edward, B.Sc.(Eng.).
Bate, Harold.
Beard, John Cecil, B.Sc. (Eng.).
Bowyer, Eric, B.Sc.Tech.
Burns, Denis Owen, B.Sc. (Eng.).
Caffin, Roy Fortescue, B.E.E.
Cardew, Arthur Haydon P.
Chen, Tai-Kwei, M.Sc. Tech.
Chester, James.
Cleaver, Richard Francis, B.Sc.
Collier, Frederick Smith.
Cutland, George.
Davies, Harold Charles.
Dewick, Francis Holland.
Earnshaw, William.

Graduates—continued.

Eastham, Sydney.
Eatock, James.
Egerton, Robert Charles.
Fortune, Fergus Watkin, B.Sc.
Gilling, Reginald Sidney, B.Sc.(Eng.).
Guscott, William James.
Hanman, Bernard Leslie G. B.Sc.(Eng.).
Harrop, Thomas Gordon C.
Hobson, Mark.
Hough, George Edward.
Howard, Bernard Scott, M.Sc.Tech.
Jagger, John Greenwood, B.A., B.Sc.
Janes, James Henry.
Khan, Muqarrab, B.Eng.
Krishnamurthy, Kadiranahally Verkataras, M.Sc.
Lamacraft, James Robert.
Mander, Norman Charles
Martin, William Hislop, B.Sc.
Mason, Gerald Linford.
Mitchell, Alexander.
Mitra, Amarendra Nath, B.Sc.
Moss, John Francis.
Myers, Harold Edgar M.
Nally, Rickard Michael.
Neil, Norman James.
Nelson, Humphrey Gordon, B.Eng.
Pasricha, Chuni Lal.
Platt, Edwin Royston.
Readman, Leonard.
Reid, Roderick Gordon, B.Sc.(Eng.).
Rose, Cuthbert Arthur.
Simmons, Kenneth George.
Singh, Saudagar, M.Sc.
Smith, Cyril Henry.
Stanforth, Bernard Leslie.
Stockwell, Reginald William.
Turner, Herbert Alexander.
Unz, Marcel, Dr.Eng.
Vickers, Jack Stanley, B.Sc.(Eng.).
Warburton, Eric.
Welton, Noel Edward.
Williams, George.
Worland, Frank James.

Students.

Andrew, William Martinus.
Andrews, William John.
Bailey, Victor Clarence H.
Barlow, Gordon Alfred.
Bhattacherji, Atul Chandra.
Biden, Guy William V.
Bivand, Eric Ernest.
Boyle, Granville H.
Brand, Theodore.
Burdett, Geoffrey Arnold T.
Burgess, Alfred John.
Burns, Ivan George.
Burrow, Charles Kenneth.
Byrom, Gerald Hobson.
Carlaw, Arthur Donald.
Choudhuri, Satyasasi.
Cohen, Jack Moses.
Coles, John Bernard.
Colvin, John Christopher.
Cooray, Lucian Bevis J.
De, Anil Chandra.
Deeley, Alfred Ronald.
Dinsdale, James Albert.
Dolan, Walter Henry.
Edwards, George Stanley.
Elavia, Bejon Gustadji.
Forbes, Thomas.
Goel, Jaqdish Parshad.
Good, Arthur Josef.
Hardy, Albert Frederick.
Harvey, Leonard.
Hodkinson, Thomas.
Hollingworth, Stephen Ian.
Hudson, Sidney William C.
Kapur, Ram Lal.
Khan, Mohd Amin.
Khanna, Madan Lal.
Kingsbury, Henry Edmund R.
Lake, Edwin Walter.
Lall, Shiam Sunder.
Lambert, Albert Peters.
Lawrence, Brian Edward J.
Lemmon, Montague John H.
Lodge, Ernest Charles.
Macdonald, Hugh Beverley.
Mackay, William Alan.
McStravick, William.
McWilliam, Alexander Renfrew.
Maggs, Dudley Richard.
Martin, Bernard Paul.
Matthews, Jack Dunn.
Meredith, Dennis Lello.
Murtha, Charles Dennis.
Nanra, Jogindar Singh.
Nightingale, Colin Walter.
Norris, Herbert Stanley.

Students—continued.

Oxley, Gordon.
Padmanabhan, Krishnier.
Pascal, Henry Philip, Jun.
Paterson, Ronald Hugh.
Patrick, Sydney Charles.
Pearce, William Bernard.
Pellow, Henry William.
Purcell, Frederick Richard.
Rajagopalam, Subramanya.
Ramaswamy, Cheyur.
Risby, Roy Millar.
Sale, Peter Anthony.
Scott, Reginald Henry.
Shanmugam, Nanjappa Chetty.
Sibal, Dev Parkash.
Siddappa, Byranna.
Singh, Harbhajan.
Subramanian, P. R.
Talwar, Balbir Singh.
Taylor, Charles Henry.
Thorndyke, Harold.
Tucker, Maurice Albert.
Verma, Rattan Chand.
Vohra, Satyr Pal.
Walker, Thomas Geoffrey.
Whitaker, Evald Mattievich.
Whiting, Frank William, B.Sc.(Eng.).
Williams, Percy Edgar.
Winter, Rioty Marshall.
Wright, Henry John.

TRANSFERS.

Associate Member to Member.

Baxter, James MacGowan.
Flemons, Sidney.
Grace, Charles Butler.
Grove, Peter Fayle, M.A.
Hailey, Guy.
Harcombe, Samuel, M.A., B.Sc.
Henzell, George Peregrine.
Higham, John Bellamy J.
Jarratt, Alfred.
Lovell, William Douglas.
Page, Albert, B.Sc.
Rawlinson, William Ferdinando, D.Sc.
Scott-Taggart, John, M.C.
Smith, Benjamin Spalding.
Willoughby, Godfrey Pountney, M.Sc.Tech.
Wood, Kenneth Lindsay.
Wrigley, Philip.

Associate to Associate Member.

Dalton, Alfred John.
Drake, Herbert Harry.
Ganguly, Shiba Prosad.
Hudson, Harold Frederic.
Munro, John.
Probert, George.
Randall, Roland.
Tremain, Arthur Geoffrey.
Westlake, Charles Redvers.
Wilcox, Edward James.

Graduate to Associate Member.

Allen, Robert Girdlestone.
Anderson, James Richard, B.Sc.(Eng.).
Ashbrook, Cecil Scott W.
Austin, Percy Ellis, B.Sc. (Eng.).
Ballard, William Edwin.
Berenbaum, Aaron, B.Eng.
Blackburne-Maze, Leonard Norman.
Blazey, Norman Claude.
Borissow, Bernard Gamon, B.Sc.(Eng.).
Butterworth, Herbert.
Coke, Robert Alexander.
Colman, Stanley Fordham.
Cooke, Conrad Reginald.
Daniel, Leslie Henry, M.Sc. (Eng.).
Davies, Arthur Cyril, B.Sc.
Duerden, Tom, B.Sc.Tech.
France, James Eric.
Freeman, Charles Davis.
Fyfe, Leslie John G., B.E.
Gurney, Norman Richard D.
Hallett, Leonard Walter.
Helman, Stanley Louis.
Huth, Edvard Friedrich A.
Jackson, Cyril Gordon, B.Sc.(Eng.).
Jones, John Cyril.
Knight, Henry Ernest.
Laing, Walter Barron.
Lewis, George Eric H.
Loasby, John Leslie.
Mackenzie, Evan John.
MacLennan, Hugh Baxter.
Matthews, Theophilus Francis.
Mitchell, Thomas Mordey.
Owen, Albert Sydney H. A.
Palmer, Edward Barry.

Graduate to Associate Member—continued.

Palmer, Hugh Leslie, B.Sc. (Eng.).
Park, John Grimes.
Patrick, Ernest Reginald, Ph.D., B.Eng.
Peachey, Francis Arthur.
Pheazey, Frank Gerald.
Pilling, John, B.Sc.(Eng.).
Rawnsley, John Ensor.
Robinson, Denis Morrell, B.Sc., Ph.D.
Rudd, Donald, B.Sc.
Scott, Colin Methven, B.Sc.
Sherwood, George Eliot C.
Smith, John Reginald P.
Storr, Clement Philip, B.A.
Sugden, Eric William, B.Sc.Tech.
Taylor, William, M.Eng.
Tompsett, Francis John.
Torond, Leonard Bernonville.
Wardle, Paul Gabriel, B.Sc. (Eng.).
Williams, Caradoc, B.Sc.
Wilton, George Smith, B.Sc.
Woodforde, John.
Woods, Reginald Arthur.
Wyborn, Edward John, B.Sc.(Eng.).

The following transfers have also been effected by the Council:—

Student to Graduate.

Abel, Harry Lewis.
Adams, Robert Whitehouse, M.Sc.
Allen, William Kenneth.
Almond, George.
Almond, James.
Askham, William Ekin, B.Sc.
Augood, Eric Basil.
Barber, Bernard Davie.
Barrass, George Smith, B.Sc.(Eng.).
Bartholomew, Lionel John W.
Beale, Beatrice Joan, (Miss) B.Sc.(Eng.).
Binks, George James.
Blackley, Victor Keir.
Bland, Frank Edward, B.Sc.(Eng.).
Bond, William Alfred, B.Sc.(Eng.).
Bousfield, Robert Hugh.
Bray, Philip Robert, B.Sc. (Eng.).
Brooks, Harold.
Browne, Frederick Bernard.
Buchan, William Sale.
Campe, William Kenneth.
Cape, Maxwell.
Chick, Percy Gaymer.
Chirnside, Hubert Stuart, M.Sc.Tech.
Clark, Colin Henry W.
Clarkson, Edward.
Clay, Ralph Arden.
Cockroft, Ernest.
Connor, George Rochfort.
Cornwell, Wilfrid Dennis.
Cullen, Peter Carver, B.Sc. (Eng.).
Damany, Laxmichand Mansingbhai, B.Sc.(Eng.).
Dittmer, William Henry.
Draper, Christopher Richard E.
D'Sa, John George L., B.E., B.Sc.
Easton, William.
Ellawela, George Edward De S.
Evans, Reginald John.
Everett, Norman Clifford.
Farmer, Frank Taylor, B.Sc.(Eng.).
Fennessy, Edward, B.Sc. (Eng.).
Fisher, Lewis.
FitzMaurice, John Cornelius.
Frank, Walter Reginald B., B.Sc.
Gibson, Maurice.
Gladwin, Francis Leighton.
Gleadle, George Musgrave.
Goldstein, Sydney.
Gosling, Ernest Bedford.
Greatorex, Hugh Twyford, B.Sc.(Eng.).
Griffin, William John.
Guest, Wilfred.
Gunton, Percy James H.
Gwyther, Hugh Banks.
Hafiz, Ahmad Adnan, B.Sc.
Hammond, John Durell Le B.
Hardman, Wilfrid Adams.
Hards, Thomas Marshal.
Hayson, Derek William R., B.Sc.
Haywood, Frank Harold.

Student to Graduate—continued.

Herriot, Archibald.
Hill, Ernest.
Hoare, Edmund.
Hopkinson, Alexander Forsyth.
Jackson, Walter Fielden.
James, Ivor Reginald J.
Jeffs, Albert Lee, B.Sc. (Eng.).
Jenkins, Howard James.
Jollyman, Herbert George, B.Sc.
Jones, David Evered H., B.Sc.
Kay, Harold Wilson, B.Sc. (Eng.).
Keech, Arthur.
Khanna, Hari Kishen L.
Kinsella, William Bernard.
Lambert, George Kempton.
Lawrence, Eric Ernest H.
Lloyd, Raymond Joseph H.
Lombard, James Stephen, B.Sc.(Eng.).
Lynch, Edmund Charles, B.Sc.(Eng.).
McDonald, Fergus Gilbert.
MacFarlane, Daniel Donald.
McLauchlan, James Romans, B.Sc.
Marslen-Wilson, David William.
Matthews, Ernest George I.
Maughfling, George Joyce.
Maxwell, Conway, B.Sc.
Mayne, Edward Adrian, B.Sc.(Eng.).
Meredith, John Gatacre, B.Eng.
Midgley, Albert Morrell.
Moraes, Arthur Denis, B.Sc. (Eng.).
Murrell, Alan Percy C.
Newman, Frank Edward.
Nicoll, Robert Scott.
Nisbet, Brian Callaway.
Nixon, Harry.
O'Hara, Kean William, B.Sc.(Eng.).
Orchard, Kenneth.
Pai, Mangalore Sarvotham, B.Sc.(Eng.).
Parsons, David Reginald.
Pask, Albert.
Paton, Ian Keith, B.Sc.
Pavletich, Frank Charles, B.Sc.(Eng.).
Pershad, Behari.
Pettifor, Percy Hayward, B.Sc.(Eng.).
Pollard, Stanley Metcalfe.
Powell, Eric Charles.
Randall, Harry John.
Rau, Bantwal Gopalakrishna, B.Sc.
Reddy, Cattamanchi Ramalinga.
Reeves, John Mackay.
Rewcastle, William.
Rice, Norman Richard, B.Sc.(Eng.).
Rogers, Anthony Peter F.
Rule, Frank Thomas, B.Sc. (Eng.).
Rule, Robert.
Russell, Vernon Arthur R.
Scott, William John.
Seth, Vallabh Das, B.Sc. (Eng.).
Shaw, Albert.
Sims, John Oliver.
Skerritt, Mark.
Skipper, Thomas Constable, B.Sc.Tech.
Somasuntharam, George Devadason, B.Sc.
Sorbie, John, B.Sc.
Stephens, Dennis.
Stoners, Alan.
Sykes, Ellis, B.Sc.Tech.
Taylor, Duncan Philip.
Taylor, Matthew Ronald.
Taylor, Raymond Wickson.
Thomas, Jack, B.Sc.
Thomson, Hubert Archer.
Thomson, William, B.Sc.
Thornton, Frederick.
Towler, William John.
Tuffnell, Reginald Charles.
Unger, John Edward.
Vickers, Valentine John, B.Sc.(Eng.).
Viswanathan, Chinnaswamy Rajam, B.Sc.
Wainman, Russell Riley.
Walters, Henry Robert.
Watkins, Arthur William M.
Webb, James Beresford.
Webb, William.
Whiston, Jack.
Widdrington, Harry.
Willis, William Frederick, B.Sc.(Eng.).
Wrate, William Arthur.
Wright, Harry Morrell.
Young, Ian Falconer.

OBITUARY NOTICES.

ROBERT BIRKETT was born on the 18th October, 1866, and was educated at Lancaster Royal Grammar School and Faraday House. On leaving the latter, he was for a short time with Messrs. Kay Brothers of Stockport, and was engaged in installing small private plants. He left Messrs. Kay Brothers in August, 1896, on being appointed an assistant engineer in the Chelsea Electric Light Co.'s undertaking. In November, 1897, he was appointed chief assistant engineer in the Burnley Corporation Electricity Department, being promoted two years later to the position of chief electrical and tramways engineer to the Corporation. During his tenure of office he converted the steam tramways to electric working. In June, 1905, he was appointed borough electrical engineer and tramways manager to the Southend-on-Sea Corporation, a position which he held until his retirement in 1929 on account of ill-health. He then went to live at Slough, where he died in September, 1934. He was elected a Member of the Institution in 1920.

ANDREW WILLIAM BLAKE, chief electrical engineer to the Willesden Borough Council, died on the 20th July, 1934. He was born at Wickham Market, Suffolk, in 1873, and was educated at Kesgrave Hall School, Ipswich. His apprenticeship was served with Messrs. Whitmore and Binyon, of Wickham Market, and with Messrs. Marshall, Sons, and Co., of Gainsborough. In 1894 he was appointed outside engineer to Messrs. Ransomes, Sims, and Jefferies, and in 1899 he became borough electrical engineer at Monmouth. From 1906 to 1909 he was employed as electrical, mechanical, and civil engineer to Messrs. Mills, English, and Co., of Swansea. He was subsequently for three years in practice as a consulting engineer in Swansea. In April, 1912, he was appointed chief electrical engineer of the Willesden municipal electric supply undertaking and held that position until his death. His 22 years' service at Willesden were years of steady progress and expansion, of more efficient working, and of improved plant and premises. He was interested in the conditions of local government service generally, and also gave much time to work on various special committees of the Institution and of the British Standards Institution. A man of original and individual outlook, he often ploughed a lonely furrow to ultimate success. He was responsible for the erection of the plant for the first electrical supply to Ayr, and he it was who set going the electrical plant employed to print the *Glasgow Herald*, long before there was a public electric supply in Glasgow. He was also engaged on the erection and operation of the electric plant of the Waterloo and City Railway and the extensions of the City and South London Railway. For a short time he assisted in the construction of the Uganda Railway. Later, he had a good deal of experience in the electrification of mines in South Wales, and he was responsible for the installation of the first 3 000-volt 3-phase supply underground. He was elected an Associate Member of the Institution in 1904, and became a Member in 1912. J. D. S.

WILLIAM BRIDGER, B.Sc.(Eng.), was born on the 9th July, 1887, and was educated at Tiffin's School, Kingston-on-Thames, and King's College, London, where he graduated. In February, 1908, he was appointed a junior assistant engineer by the Newcastle-on-Tyne Electric Supply Co. In December, 1909, he became demonstrator in mechanical and electrical engineering at the Dundee Technical College, a position which he held for about 15 months. On leaving Dundee he again took up power supply work as assistant shift engineer in the West Ham Corporation Electric Supply Department, being later promoted to the position of senior charge engineer. In April, 1920, he was appointed chief lecturer in electrical engineering at the West Ham Municipal College, a position which he held for a number of years. He died on the 10th August, 1934. He joined the Institution as a Student in 1906, and was elected a Graduate in 1913, an Associate Member in 1917, and a Member in 1925.

ARTHUR PRINCE CHATTOCK was born at Solihull, Warwickshire, on the 14th August, 1860, and died at Clifton on the 1st July, 1934. He was the eldest son of Mr. R. S. Chattock, a well-known artist and etcher, and belonged to an old Warwickshire family. He was educated in London at University College School and, after spending two years on the Continent, took the engineering course at University College under Sir Alexander Kennedy, and also studied physics under Prof. Carey Foster. After a short period in the works of Messrs. Siemens Brothers at Woolwich, he welcomed an appointment in 1885 as demonstrator at University College, Bristol, where he taught physics and electrical engineering under Prof. J. Ryan. In 1887 he went to Liverpool University as demonstrator under Prof. (now Sir) Oliver Lodge, and in 1889 he returned to Bristol as lecturer in physics. Four years later he was raised to a professorship in physics and electrotechnology. This post he held until 1909, when he retired. In recognition of his services he was awarded the honorary degree of D.Sc. in 1911, and later was created an Emeritus Professor. In 1919 the University offered him an independent post with no responsibilities but the prosecution of research. This post he held until 1924. He was elected a Fellow of the Royal Society in 1921. Quite recently the University of Bristol resolved to endow a permanent Chattock Research Studentship in the Wills Physical Laboratory in recognition of his work. He became an Associate of the Institution in 1882 and a Member in 1893.

The following note by Sir Oliver Lodge will give an

idea of his early activities, and an account of his later research work will be found in the obituary notice written by Dr. A. M. Tyndall for the Royal Society.*

R. A. C.

Note (11*th July*, 1934) *by Sir Oliver Lodge*.

"A. P. Chattock came to me as demonstrator, with a high testimonial from my old friend Carey Foster, who said that he was his own worst enemy and that his modesty really stood in his way, but that nevertheless I should find him a first-rate man and full of ideas: and so it proved. He had already invented the magnetic potentiometer before coming down, and he rigged up one for me to try soon after he came down, winding a single layer of thin wire closely on a solid rod of india-rubber, connecting it to a galvanometer, and then bending the rod quickly, so that one end moved from a place where you desired to measure the potential till it touched the other end, the throw of the galvanometer needle being an indication of the change of magnetic potential, or the number of magnetic lines which had been cut by the solenoid. Another thing he devised, a closed magnetic circuit, at the centre of which was suspended an electrostatic needle, which could be deflected slightly when the magnetic circuit was reversed; a very small residual effect: virtually the magnetic analogue of a tangent galvanometer, with the electric and magnetic elements interchanged.

"I was at the time working at the electric oscillations of a Leyden jar circuit, which Chattock insisted must be producing waves in the ether. That, indeed, Hertz soon afterwards proved they did, in a very admirable manner. (See the report in the *Electrician* of the Meeting of Section A of the British Association at Bath in the year 1888.) I don't believe I should have seen the evidence for electric waves so clearly had it not been for Chattock's encouragement.

"One of the researches he took up and pursued afterwards at Bristol was the discharge of electricity from points. [See *Philosophical Magazine*, vol. 32 (5), 1891, and later vol. 20 (6), 1910.] He saw more in this phenomenon than I did, and probably silently anticipated some of the conclusions to which J. J. Thomson was led in his brilliant series of experiments which resulted in the discovery of the electron.

"I was glad when the University of Bristol offered Chattock a chair, for then he could pursue his ideas, less hampered by elementary teaching than we were at Liverpool."

PROFESSOR WELLESLEY CURRAM CLINTON, B.Sc., died on the 18th August, 1934, at the age of 63. His death must have caused great regret and grief to all his old students and to those members of the Institution who knew him and had profited by his teaching and help at University College, London. He was born in London on the 28th October, 1871, and was educated at the Central Foundation School, Cowper-street, London. He received his early scientific training, between 1886 and 1891, at Finsbury Technical College under the late Professors Ayrton and Perry, and his practical training at the works of Messrs. Bertram Thomas, Manchester. In 1894, when the new engineering laboratories at University College, London, were opened he was appointed assistant to Sir Ambrose Fleming, then the professor of electrical engineering, whom he assisted in the equipment of the teaching appliances, the organization of the electrical engineering departments, and the practical teaching. He soon showed his ability in this work and his practical skill in the construction of apparatus. He had unusual abilities as a teacher, and early secured the respect and affection of his students. In 1906 he was appointed assistant professor. Long before that he had taken the degree of B.Sc. with first class honours in the University of London. In 1920 he was made a Fellow of University College, and in 1926, on the retirement of Sir Ambrose Fleming from the chair of electrical engineering at University College, London, Clinton was appointed by the Senate of the University as his successor. In 1934 he was elected Dean of the Faculty of Engineering, but he did not live to take up the duties of the office.

His devotion to College work did not leave him time for much research work; nevertheless, his contributions to it were of value. He paid particular attention to photometry, to illuminating engineering, and to electric wiring. He very successfully carried out some important work in connection with the electric lighting of the College. He translated into English in 1912 a German book by Dr. Bloch on the "Science of Illumination," and in 1902 he wrote a book on electric wiring. He was also a contributor to a work called "Modern Electrical Engineering," and was the author of various papers before the Physical Society and the Illuminating Engineering Society. During the War he carried out valuable researches for the Ministry of Munitions on night gun-sights and other photometric questions. He was associated with Sir Ambrose Fleming in researches on the measurement of small capacitances and inductances at high frequency, and in the measurement of standard photometric lamps.

He was elected an Associate of the Institution in 1896, an Associate Member in 1899, and a Member in 1912.

J. A. F.

WILLIAM COTSWORTH was born at Manchester on the 28th March, 1871, and died on the 15th April, 1933. He received his technical education at Finsbury Technical College under Silvanus Thompson. He commenced his career with a firm of consulting engineers in Manchester, and was subsequently appointed assistant manager and, later, manager of the Manchester branch office of Messrs. Drake and Gorham. During his seven years' service with this firm he was responsible for many of the very early country-house electrification schemes. In 1902 he was appointed by the then newly-formed Calico Printers' Association as their first electrical engineer; he was promoted to the position of chief engineer of the Association in 1919. Noteworthy among his achievements in connection with the engineering side of the textile finishing trade was his work in connection with the economic deposition of copper on cast iron, and his study of the economies in power costs to be derived from combined power and heating installations. In 1912 he made an agreement with the Manchester

* "Obituary Notices of Fellows of the Royal Society," No. 3, December 1934.

Corporation to buy exhaust steam from their Electricity Department for the heating of the new central offices of the Calico Printers' Association. He subsequently equipped the Association's works with some thousands of kilowatts of steam-driven generating plant, the exhaust steam from the plant being used for process work. Although engrossed in his professional work, he had many other interests in life, among them being his activities for the welfare of crippled children. His help or advice was always available both to his colleagues and to his subordinates; such help he gave with complete unselfishness and often at considerable sacrifice to himself. He became an Associate Member of the Institution in 1901 and a Member in 1912. C. J. E.

COLONEL PERCY BARBY CROWE was educated abroad and also at King's College, London. He served his apprenticeship with the Barrow Shipbuilding and Engineering Co. from 1883 to 1886, and then went to sea as an engineer on the S.S. "Liscard." From 1887 to 1889 he was employed as a draughtsman by the Naval Construction and Armaments Co. (later Messrs. Vickers, Son, and Maxim). In 1889 he was appointed an assistant engineer by the Metropolitan Electric Supply Co., and was later promoted to superintending engineer. In 1895 he joined Messrs. W. H. Allen, Son, and Co., and had sole charge of the London office. He was appointed a director of that company in 1906. At the outbreak of war he served with the 1st Battalion of the London Regiment, and later had various staff appointments in France. He died on the 12th December, 1933, at the age of 70. He joined the Institution as an Associate in 1889, and was transferred to full membership in 1907.

EDGAR ISAAC EVERETT was born in 1869 at Metfield, Suffolk, and died on the 19th April, 1934. Always keenly interested in mechanical matters, he entered the factory of the Cambridge Instrument Co. at the early age of 13, remaining with them until 1887 when he joined Mr. Frank Nalder, who was taking over the commercial-instrument side of the business. In 1896 he started on his own account as a manufacturer of various forms of measuring instruments and experimental mechanical devices, with a small workshop in Albemarle Street, Clerkenwell. In 1900 he was joined by Mr. K. Edgcumbe in the formation of the firm of Everett, Edgcumbe, and Co., with premises in Charterhouse Square, Clerkenwell. The firm specialized in the manufacture of electrical measuring instruments for industrial purposes. Owing to its rapid growth the concern was forced to move shortly afterwards to Great Saffron Hill, Holborn, and in 1905 to Hendon, where the present works were built. In 1906 the business took the form of a limited liability company, Mr. Everett becoming joint managing director. He held this post until his retirement in 1929, owing to failing health. Throughout all these years the responsibility for the mechanical design and construction of the firm's products had devolved almost entirely upon him. Always somewhat impatient of theoretical considerations, he possessed in a marked degree that intuitive sense of proportion which is essential to the success of every engineer and which no amount of theoretical training can ever replace. Nor were his energies solely devoted to measuring instruments. In 1909, fired with enthusiasm by Bleriot's successful flight across the English Channel, he built himself an aeroplane, in which several trials were made in some fields near the works at Colindale. Unfortunately (or possibly fortunately, since flying was a risky business in those days) the engine proved lacking in power and the experiments were abandoned, the ground being taken over by the London Aerodrome Co. and later by the Royal Air Force. During the war, attracted by the ready-made aerodrome, a large number of aeroplane manufacturers settled in Hendon, which, from such small beginnings, became the most important flying centre in the country. Mr. Everett was elected an Associate of the Institution in 1898, an Associate Member in 1899, and a Member in 1913. K. E.

JOHN JOSEPH FAHIE, one of the Institution's oldest members, died at Broughton-in-Furness on the 12th June, 1934. Born at Tipperary in 1846, he was educated at the classical seminary of Mount Melleray, Co. Waterford, at St. Joseph's Seminary, Clondalkin, Co. Dublin, and at the Classical University of Ireland. He received his technical education at evening classes in London, which he attended from 1865 to 1867 while in the service of the Electric and International Telegraph Co. In 1867 he went to Persia on the staff of the Indo-European Government Telegraph Department, being appointed superintendent of the cable station at Jask. The fruits of his experience there were embodied in three papers* which appeared in the *Journal* between 1874 and 1876. The last of these describes the system of duplex telegraphy which he developed and used with success on the Shiraz–Teheran line. He served at various stations on the Persian Gulf until early in 1875, when he was transferred to the Persian landline section of the Department. In 1874 he offered to the I.E.E. Council the sum of £100 for the formation of a Premium fund, and as a result the Fahie Premium, which is awarded for papers dealing with telegraphy and telephony, was instituted. Mr. Fahie contributed numerous articles to the technical Press on telegraphic and telephonic subjects; his most outstanding achievement in this direction was the discovery and publication† of the manuscripts of Edward Davy, dealing with the electric telegraph which he had invented in 1836. A keen student of the history of science, Mr. Fahie was a prolific writer on the early work of Galileo, and at the time of the Faraday Centenary Celebrations he contributed a valuable paper‡ to the *Journal* on the subject of the progress in magnetism, electricity, and electromagnetism, prior to the great discoveries of 1831. He was the author of the following books: "A History of Electric Telegraphy, to the year 1837" (1884); "A History of Wireless Telegraphy, 1838–1899" (1899); "Galileo: his Life and Work" (1903); "Memorial of Galileo Galilei, 1564–1642; Portraits and Paintings, Medals and Medallions, Busts and Statues, Monuments and Mural Inscriptions" (1929). He was elected an Associate of the Institution in 1873, and a Member in 1877.

* *Journal I.E.E.*, 1874, vol. 3, pp. 80 and 372; and 1876, vol. 5, p. 473.
† *Electrician*, 1883, vol. 11, pp. 181, 206, 224.
‡ *Journal I.E.E.*, 1931, vol. 69, p. 1331.

PROFESSOR JAMES GORDON GRAY, D.Sc., F.R.S.E., was born on the 19th May, 1876, and died on the 6th November, 1934. He was educated at Friars School (Bangor), the University College of North Wales, and the University of Glasgow. In 1896 he joined the staff of the General Post Office and worked for three years under the late Sir William Preece. Returning to the University of Glasgow, he took the degree of B.Sc. in 1901, obtaining special distinction in mathematics, natural philosophy, electricity, and laboratory practice. The University later conferred on him the degree of D.Sc. in recognition of his published work in the field of applied physics. In 1903 he took up the position of lecturer on Natural Philosophy at Glasgow, where in 1920 he was appointed to the Cargill Chair of Applied Physics. He was an authority on the application of the gyrostat to practical problems, and carried out a long series of researches on the use of gyroscopes in aerial and marine navigation and national defence. Much of this work was done in collaboration with his father, the late Prof. Andrew Gray, whom he assisted in the experiments shown when the latter delivered the Sixth Kelvin Lecture ("Lord Kelvin's Work on Gyrostatics") before the Institution in 1915. He also made a number of investigations on magnetic phenomena at low temperatures. He was elected a Member of the Institution in 1925.

JOSEPH PLATT HALL, son of the late William Hall, surgeon, of Salford, was born on the 8th September, 1864, and died on the 10th June, 1934, aged 69 years. On leaving school he was in 1881 apprenticed for 5 years to Messrs. Mather and Platt, of Salford. He passed through all the departments of the firm, but was especially attached to the electrical side, which in this country was not then very far advanced commercially. He took out his first patent in December, 1884, in conjunction with the late Holbrook Cushman, for the Cushman–Hall dynamo. Before leaving Messrs. Mather and Platt he went to Russia for that firm and erected electrical plant at Schlusselburg. He was subsequently employed by the Electric Portable Battery Co., Salford, as manager for about two years. Entering into partnership in Oldham with the late Mr. S. Charlesworth, under the name of Charlesworth, Hall, and Co., he began to make dynamos, high-speed steam engines, and searchlight projectors. The firm was one of the first in this country to supply complete portable searchlight plants for the use of ships passing through the Suez Canal. In 1892 he started in business on his own account as J. P. Hall and Co., at Werneth, Oldham. The company gradually increased in size, and carried out contracts for the Government and for the principal engineering firms throughout the country. From its earliest days the firm specialized in the manufacture of motors for use in connection with electric cranes. When war broke out the firm was very early Government-controlled, and throughout worked practically day and night on the manufacture of electric motors for munition factories. Mr. Hall was not only an electrical engineer but also a mechanical engineer, and the combination of these qualities was the keynote of his firm's success. He sold the business in December, 1931, and retired to live in Shropshire, where he died. He joined the Institution as a Member in 1900, being transferred from membership of the Northern Society of Electrical Engineers. He was very interested in archaeology and was a Fellow of the Society of Antiquaries. A. G. H.

LEONARD WILLIAM HOLMES was born at Newcastle-on-Tyne in 1859, and died at Worthing on the 21st November, 1933. Part of his early life was spent in Australia, but a year or two after the founding, in 1883, of the firm of J. H. Holmes and Co. as electrical engineers in Newcastle-on-Tyne, he returned to England and opened their London office, of which he had charge for many years. In those early times, nearly half a century ago, pioneering was the order of the day, and he had his share in many new and interesting developments in electrical engineering. His geniality and bonhomie will be vividly recalled; his were the manner and bearing that make men popular, and his persistence, added to his affability, was a great asset to him in his part in the building-up of his firm's business. One of the important early installations with the furnishing of which he was connected was that of Messrs. Maple and Co., of London. It was carried out in 1888, and was a notable generating equipment in its day, before electric supply had been generally brought to the doors of consumers by public undertakings. In many other directions he helped to spread the use of electricity; in 1897 he negotiated the acquisition by his firm of the patent rights for "Lundell" motors, which had a great vogue in their application to industrial electric drives, particularly in printing-works and newspaper-offices, where the development of the Holmes–Clatworthy duplex-motor principle led to the widespread adoption of the electric drive both at home and abroad. Mr. Holmes retired from the firm of J. H. Holmes and Co. in 1908, after an illness, and subsequently turned his attention to matters outside the electrical industry. He was elected a Member of the Institution in 1889. T. C.

WALTER BERNARD HOPKINS was born on the 19th July, 1863, and died on the 14th April, 1934. He was apprenticed to his father, the late Mr. G. D. Hopkins, a civil engineer, for five years, spending a year of this period as a resident engineer on the Ramsey–Somersham Railway. From 1887 to 1896 he was employed under his father on the construction of the East and West Yorkshire Union Railways and of various tramway systems in London. In 1896 he became a partner in his father's business. He was subsequently responsible for the plans of numerous electric tramway systems, including the Bradford–Leeds, Aldershot–Farnborough, Dundee–Broughty Ferry, Camborne–Redruth, Glossop, and Bath. At a later date he was engaged on engineering work in connection with the Maidstone–Ashford Railway. In addition, he promoted and successfully carried through the electric lighting schemes of several towns. A director for some years of Edmundsons' Electricity Corporation, the Folkestone Electricity Supply Co., and the Lancashire Electric Power Co., he also served as consulting engineer to Messrs. Siemens Brothers, for whom he undertook a world tour in 1918–19. He was elected a Member of the Institution in 1903.

CYRIL FRANCIS MACKNESS was the son of the late Canon George Mackness, D.D., of Broughty Ferry, Angus. He was educated at the High School, Dundee, and although he left there to join the staff of the local branch of the Bank of Scotland, where he remained for several years, he had acquired such a taste for engineering in the school workshops that, in the face of much opposition, he apprenticed himself to the Sunderland Forge and Engineering Co., in 1898. Two years later he joined Messrs. Bruce Peebles and Co. in Edinburgh, and became superintendent of the testing department. During all this time, he continued his studies at the Durham College of Science, Newcastle-on-Tyne, and later at the Heriot Watt College, Edinburgh, until his health gave way. Even this was made use of, and a series of sea voyages followed, during which he served as electrician or in other capacities. These voyages took him to South Africa and the Argentine. In 1902, being fully restored to health, he became assistant to Messrs. Carruthers and Elliot, consulting engineers to the West Australian and New South Wales Governments, and was engaged on important inspection work in Germany and Switzerland. He subsequently joined the A.E.G. of South Africa, and as that firm's assistant manager in 1904 he helped to develop for them a world export business. During the next 10 years, a period of great electrical development, he was entrusted with many important missions, visiting for his firm the United States, Mexico, and the whole of South Africa and Rhodesia. In 1914 he became assistant manager of the electrical department of Messrs. Vickers, and in 1919 he formed and became chief engineer of their hydro-electric department. Later he was placed in charge of the company's general engineering department. By this time he had become an engineer of the widest experience. His practical and inventive ability, his business training, his sound technical knowledge, his literary gifts, and his mature judgment, coupled with great charm and dignity of manner, and an unfailing sense of humour, well fitted him to act as a consultant, and this he became in 1923. His firm carried out many important works for clients from England, the Continent, the United States, and Canada. Among these were hydro-electric works in Nigeria and Colombia, important missions to Germany, Austria, and Italy, much mining and dredging electrification work in Nigeria and Malaya, and steam power-station work in South Africa and Australia. Mackness, who was in his 59th year, died after a brief illness on the 17th December, 1933. He leaves a widow and one son. He was elected an Associate Member of the Institution in 1904 and a Member in 1921.

The procession of life is of great beauty, and none adorns it more than Mackness. He encountered great difficulties and met and overcame them cheerfully. A man of scrupulous honesty, he saw the good (sometimes the only good) in men of all estates of life, and there must be literally hundreds of engineers and others the world over who have received rich help, advice, and encouragement from him. None was forgotten and none will forget.

J. F. S.

WILLIAM FRANCIS MUDIE MYLAN was born on the 30th January, 1881, and died on the 29th October, 1934. He was educated privately, and received his engineering training at University College, Sheffield, where in 1901 he was appointed to the dual position of demonstrator and engineer in charge of the electrical plant. In 1903 he joined the Sheffield staff of the British Westinghouse Co. as a sales engineer, and in 1906, after spending a short period in the company's testing department at Manchester, he was promoted to the position of sales manager at Sheffield. Resigning this appointment in 1919, he founded the business of Mylan and Smith (Engineers) Ltd., Sheffield, and undertook the selling and installation of electrical and other engineering plant. In 1930 he set up in business on his own account and became the Sheffield representative of the Metropolitan Cable and Construction Co. He was elected a Student of the Institution in 1902, an Associate Member in 1907, and a Member in 1926.

HARRY LEONARD PERCY was born on the 10th April, 1882, and was educated at St. Paul's Preparatory School, London, and St. Peter's School, Weston-super-Mare. He received his technical training at Faraday House, during the course of which he was for a time with Messrs. Robert Stephenson and Co., Newcastle-on-Tyne, and in the Blackpool Corporation Electricity and Tramways Department. In January, 1902, he served for a short time as assistant mains superintendent at West Hartlepool, and then was successively appointed as engineer-in-charge in the Wimbledon Electricity Department, assistant engineer in the Chesterfield Corporation Electricity Department, and deputy borough electrical and tramways engineer to the Corporation of Chesterfield. Whilst at Chesterfield he also lectured on electric lighting and power distribution at the Municipal Technical School during the session 1905–6. In July, 1906, he was appointed assistant engineer in the employ of the Colombo Electric Tramways and Lighting Co., and occupied that position for a number of years. He retired in 1926 and settled down at Great Missenden, Bucks, where he died on the 15th June, 1934. He joined the Institution as a Student in 1899, and was elected an Associate in 1904, an Associate Member in 1909, and a Member in 1913.

THEODOR PETERSEN was born at Birmingham in 1868, his father being the Danish Consul and one of the leading merchants of that city. He never lost touch with Birmingham and its people, retaining to the last a deep affection for both. Educated at Clifton and at Zurich Polytechnic, he served his apprenticeship with Messrs. Marshall, Sons, and Co., of Gainsborough, subsequently joining the staff of the Brush Co. He married the daughter of the late Mr. James Marshall, the head of the Gainsborough firm, and began his business career by cultivating the interests of that company in Denmark, his knowledge of the language and of the ways of the people being of great help. Desirous of settling in England he got into touch with the Callender Co., joining them in 1894 as assistant to Mr. T. O. Callender (now Sir Thomas Callender). The company's business was at that time small in extent, but was developing rapidly, and Petersen and Sir Thomas worked together to further that development during the whole of their 40 years'

association. No two men could have kept in closer touch. They occupied adjoining rooms. All matters of importance were discussed between them before being acted upon or placed before the Board. Their association was of the closest and most friendly nature, and any differences of opinion that arose were freely discussed and reconciled with never a shadow of ill-feeling.

Shortly after he joined the company it was decided to extend their operations to the Continent, and his thorough knowledge of German and Danish assisted materially in the development of the firm's interests in Germany and elsewhere. As a result of visits to various parts of the Continent, offices were opened in Dusseldorf and, later, in Hamburg. Together Sir Thomas and Petersen were able to build up the closest possible association with the leaders of the electrical industry in Germany, an association which has continued to the present day and which has contributed so largely to bringing about that mutual understanding which has been so beneficial to the industry of both countries. This happy result was due in no small measure to Petersen's knowledge of the language and his experience of, and sympathy with, the people on both sides of the North Sea. It was not only Petersen's international work that served us all in such good stead, but his equally successful negotiations in this country, aided by the affection and esteem in which he was universally held.

In 1930 he was appointed assistant managing director of the company. During the last two or three years he was in indifferent health. A voyage to the East in the early part of this year in search of a change and sunshine had to be broken in Egypt. The benefit obtained was disappointing and the end came on the 2nd November, 1934, with unexpected suddenness. To those of us who knew him and who relied so much upon his kindly advice, knowledge, and experience, his loss is irreparable, whilst the large circle of friends from all parts of Great Britain, as well as from the Continent, who went to his funeral at Esher to pay their last respects was a telling testimony to his sterling character and worth. He was elected an Associate of the Institution in 1891, and a Member in 1905. T. O. C.

KENNETH PRESTON was born on the 31st March, 1887, and died on the 28th January, 1934. He was educated at Nottingham Grammar School and Bowdon College, Cheshire, and later attended evening classes at the Manchester School of Technology while serving his apprenticeship from 1903 to 1907 with the British Westinghouse Electric and Manufacturing Co. On the completion of his apprenticeship he was employed by the same company from 1907 to 1910, first on general erection work in the South Wales district, and subsequently as sales engineer at Cardiff. In 1910 he went to Bombay as acting manager in the Bombay office of Messrs. F. and C. Osler. A year later he obtained employment with Messrs. Siemens Brothers Dynamo Works as assistant engineer in their Calcutta office, where he was responsible for the preparation of schemes for town-lighting, jute-mill electrification, and mining installations. He also served as resident engineer with Messrs. Siemens Brothers for the Delhi-Durbar power house. In 1915 he was appointed by the Government of India chief electrical engineer of the North-Western Railway with headquarters at Lahore, Punjab, a position which he held for over 10 years. During the war he first served as Lieutenant and Staff Captain of Military Works in Mesopotamia, and subsequently as Staff Captain in the chief mechanical engineers' branch of the War Office, and was responsible for the purchase of electrical and mechanical machinery for France, Egypt, and Mesopotamia. In 1927 he was appointed an Electrical Inspector of Factories. He joined the Institution as a Student in 1905, was elected an Associate Member in 1912, and was transferred to full membership in 1923.

CALVIN WINSOR RICE was born on the 4th November, 1868. After graduating at the Massachusetts Institute of Technology he became an apprentice at the works of the Thomson-Houston Electric Co., at Lynn, Mass. In 1892, after the amalgamation of this company with the General Electric Co., he was appointed assistant engineer in the power and mining department of the works at Schenectady, being promoted in 1895 to the position of district engineer to the company, with headquarters at Cincinnati. He resigned from the General Electric Co. shortly afterwards to become chief engineer at the Silver Lake Mines, Colorado, where he installed and was in charge of the operation of electric power and lighting equipment. In 1897 he became associated, as consulting engineer, with the Anaconda Copper Mining Co. The following year he went to New York as electrical engineer to the King's County Electric Light and Power Co., and was later engaged on power-supply and traction work under the New York Edison Co. and its associated companies. In 1902 he became second vice-president and manager of the Nernst Lamp Co. He returned to the General Electric Co. in 1903 as consulting engineer and specialized in steam-turbine work. In 1907 he was appointed secretary of the American Society of Mechanical Engineers, and held that position until his death, which occurred on the 2nd October, 1934. He was elected a Member of the Institution in 1903.

HERBERT WALTER RIDLEY died on the 27th December, 1933, at the age of 65. He was educated at Taunton School and received his electrical training at Finsbury Technical College, and with the firm of John Massey and Co., being engaged with the latter on several important early installations of electric lighting, including that at Buckingham Palace. He entered the service of the London County Council in 1891, and was at first engaged on installation work; subsequently he was appointed an inspector under the various Electric Lighting Acts and Orders for London, being concerned with the Council's responsibilities under these in respect of such matters as loans to municipal electricity undertakings, changes in the systems of supply, and the maintenance of "declared pressure"; he was also responsible for the Council's laboratory for the testing of "disputed" meters and for the settlement of disputes between consumers and supply undertakings in the county. He suffered continuously from a serious accident received while on anti-aircraft service during the war, and died

within a few months of his retirement from the Council's service. He joined the Institution as a Student in 1888, and was elected an Associate in 1890, an Associate Member in 1912, and a Member later in the same year.

E. R.

JOHN ARTHUR RUDD was born at Penrith on the 28th August, 1864, and died at Glasgow on the 14th November, 1933. Educated at the Mansion House School, Penrith, he went to Scotland in 1881 and spent a short period in Edinburgh studying medicine. Later in the same year he entered upon a five-year apprenticeship with Messrs. Robert Napier and Sons, of Glasgow, at the conclusion of which he spent a further period of three years with the firm as assistant engineer in their experimental section. In 1889 he started in business on his own account at Glasgow under the name of J. A. Rudd and Co. He at first devoted his attention to the inspection of machinery for export, but later took up electrical work, specializing in the electric lighting of hotels, ships, and railway stations. His electrical activities brought him in contact with the Telegraph Manufacturing Co., of whose Scottish branch he became in 1892 the founder and first manager. When the firm amalgamated with the British Insulated Wire Co. he had charge of the combined operations in Scotland of the two companies. In 1901 he took over the additional appointment of engineer and manager for Scotland of Messrs. Browett, Lindley, and Co., a position which carried with it responsibility for the installation of a large amount of electrical plant in central stations and public works. At the time of his death he was the Scottish representative of Messrs. Richardsons, Westgarth, and Co., Messrs. Sulzer Brothers, and Messrs. John Hind and Sons. He was elected a Member of the Institution in 1904.

FRANK JULIAN SPRAGUE died in New York on the 25th October, 1934, at the age of 77. Born at Milford, Connecticut, on the 25th July, 1857, he entered the Naval Academy, Annapolis, in 1874, and in 1880 carried out electrical work at the Brooklyn Navy Yard. Two years later, at the age of 25, he represented the United States Government at the Crystal Palace Electrical Exhibition, where he served as a member of the Jury of Awards. Leaving the Navy on his return to the U.S.A., he became an assistant to Mr. T. A. Edison, under whom he was engaged on the planning of electrical distribution systems. A year later he formed the Sprague Electric Railway and Motor Co. and developed the application of the electric motor to industrial uses. He next turned his attention to the problem of designing a motor for use in electric traction, a problem whose solution he embodied in the first successful electric street railway, which he evolved for the Union Passenger Railway Co. in 1887. This achievement he followed up by designing a number of experimental electric locomotives for elevated railways in New York. He subsequently invented the Sprague electric elevator, and, in 1895, the multiple-unit system of electric train control, both of which were widely adopted. Several concerns with which he was connected, including the Sprague Electric Co. which he formed in 1897, were merged in 1902 in the American General Electric Co. He later became president of the Sprague Safety Control and Signal Corporation and the Sprague Development Corporation. He was elected a Foreign Member of the Institution in 1899, and a Member in 1911. In 1892 he was elected president of the American Institute.

SIR GEORGE SUTTON died on the 30th April, 1934, and his death has removed yet another of the personal links with the pioneering days of electrical development. He secured his claim to fame on the commercial and industrial side of the industry, but although not a scientist himself he was responsible for the inauguration of much investigation by efficient scientists, physicists, and chemists, in electro-technology, particularly in connection with cables and wires. He was appointed Secretary to W. T. Henley's Telegraph Works Co. in 1881 when he was 24 years of age. The company was then a small undertaking, which had been incorporated in 1880 in an endeavour to rescue something from the collapse of the business of William Thomas Henley, which had been operating since 1837. When Sir George Sutton became the company's secretary the concern was continually in financial straits, and the task before him would have discouraged many of more mature years and greater business experience. Henley died in 1882 and from that time the control and development of the company was virtually the responsibility of Sir George Sutton. His common sense, determination of character, and unbounded energy, eventually brought the company into a sound financial position. It was some years after the incorporation of the company before there was a reasonable demand for cables for lighting and power, and in the meantime the company continued the manufacture of submarine cables and telegraph wires and secured a number of submarine cable contracts. Thus, when electricity developed along the lines of telephony and lighting the company was in a position to put down plant to meet that demand. In 1886, five years after his appointment as Secretary, he was made Manager of the company, and in 1893 he was elected to the Board and became Managing Director. In 1910 the shareholders presented him with his portrait in oils, painted by Sir Luke Fildes, R.A.; in 1918 they elected him Chairman of the Board, and, on his retirement from this office in 1932, he was given the courtesy title of President of the company. He was elected an Associate of the Institution in 1886 and a Member in 1901; and he was created a Baronet in 1922.

Throughout his life he was particularly generous in his benefactions to various charitable objects and institutions, including the Benevolent Fund of the Institution and the Electrical Trades Benevolent Institution, to both of which he also left a bequest. He did much to improve the welfare, comfort, and security of his staff and workpeople, and, among other things, he inaugurated pension funds for the staff and benefit funds for the hourly paid workers. One thing of which he was proud was the part he took, with other leading figures in the cable-making industry, in the formation of the Cable Makers' Association in 1898. He and others realized that the intensive competition that had developed could only result in reduced quality,

cable breakdowns, and loss of confidence in British cable makers. The C.M.A. was the first of such organizations in the electrical industry, and the part it has played in securing minimum standards of quality, in standardizing sizes and specifications, and in co-operative work with the Institution and other bodies, has resulted in British cables being regarded as the highest standard in the world. He took a great interest in the Royal Society of Arts and helped its work financially on more than one occasion. He was a past Chairman of its Council and a Vice-President of the Society. Sir George left no heir, and his wife predeceased him in 1931. M. H.

LAWRENCE BEVERLEY TRANT, who was born in Yorkshire on the 31st March, 1848, was of French extraction on his mother's side and was educated at St. Pierre-Église, Normandy. He went to sea when he was 12 years of age and visited, among other countries, Australia, China, Japan, and the United States. After three years at sea, however, he decided to take up telegraphy. In 1868 he went out to the Argentine with his brother Peter and several other young telegraph engineers, and installed telegraphs in various parts of that country. He himself was for many years at the headquarters in Buenos Aires of the Provincial Telegraph Department. He came to England owing to the illness of his mother, but on her death he returned to Buenos Aires and took up consulting work as a telegraph engineer on his own account. Later, for a period of about 5 years, from 1910 to 1915, he resided in London, but he again returned to Buenos Aires in 1915, where he died on the 7th July, 1933. He was an excellent linguist and could speak fluently in French, Italian, and Spanish, as well as English. He was one of the oldest members of the Institution, having been elected a Foreign Member in 1873 and a Member in 1911. He served on the Committee of the Argentine Local Centre in 1920–21.

NORMAN JAMES WILSON, who died on the 31st July, 1934, at the age of 60, was educated at Merchant Venturers' Technical School, Bristol, the Technical College, Bristol, and the Central Technical College, South Kensington. After serving for a short time in various departments of the works of the Electric Construction Co. at Wolverhampton, he was appointed in 1896 chief assistant in the testing department. In 1900 he entered the service of the British Westinghouse Co. and spent 2 years in the works of the American Westinghouse Electric and Manufacturing Co. at Pittsburgh, U.S.A. In 1902, when the British Westinghouse works were opened at Trafford Park, Manchester, he was appointed chief of the electrical testing department, a position which he held for 4 years, during which time he was responsible, among other work, for the testing on site of the generating and substation plant in connection with the electrification of the District Railway, and also at other power stations. He later assisted the chief designer of the British Westinghouse Co. in developing alternating-current turbo-generators, and subsequently set up as a consulting engineer with Mr. Oulton. He joined the Institution as a Student in 1895, and was elected an Associate in 1897, an Associate Member in 1899, and a Member in 1907.

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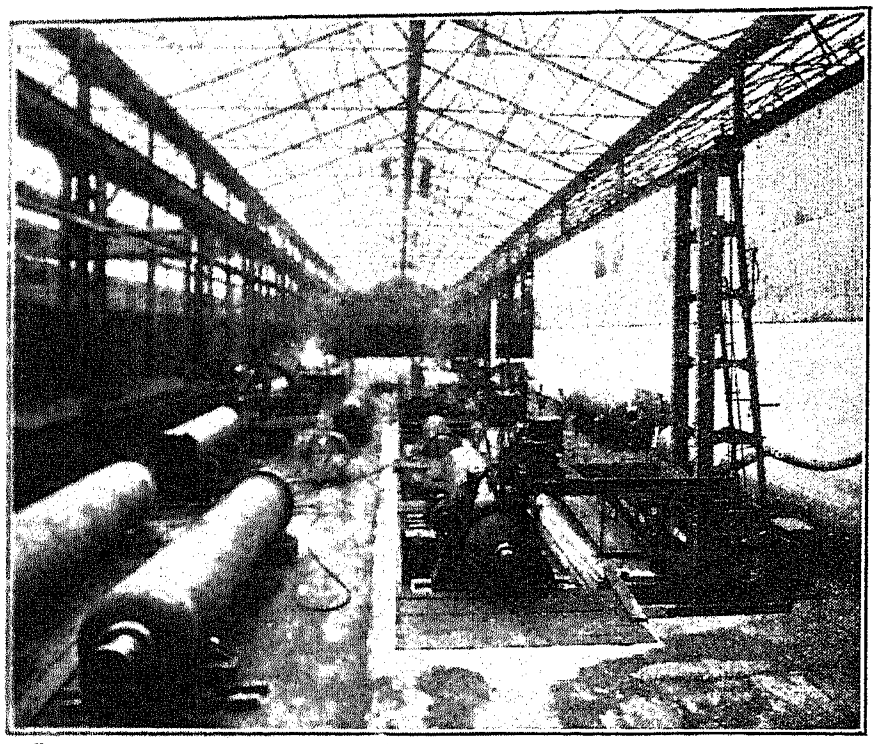

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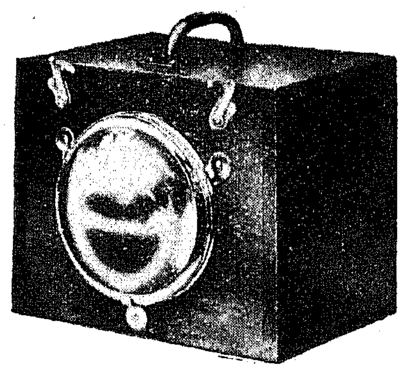

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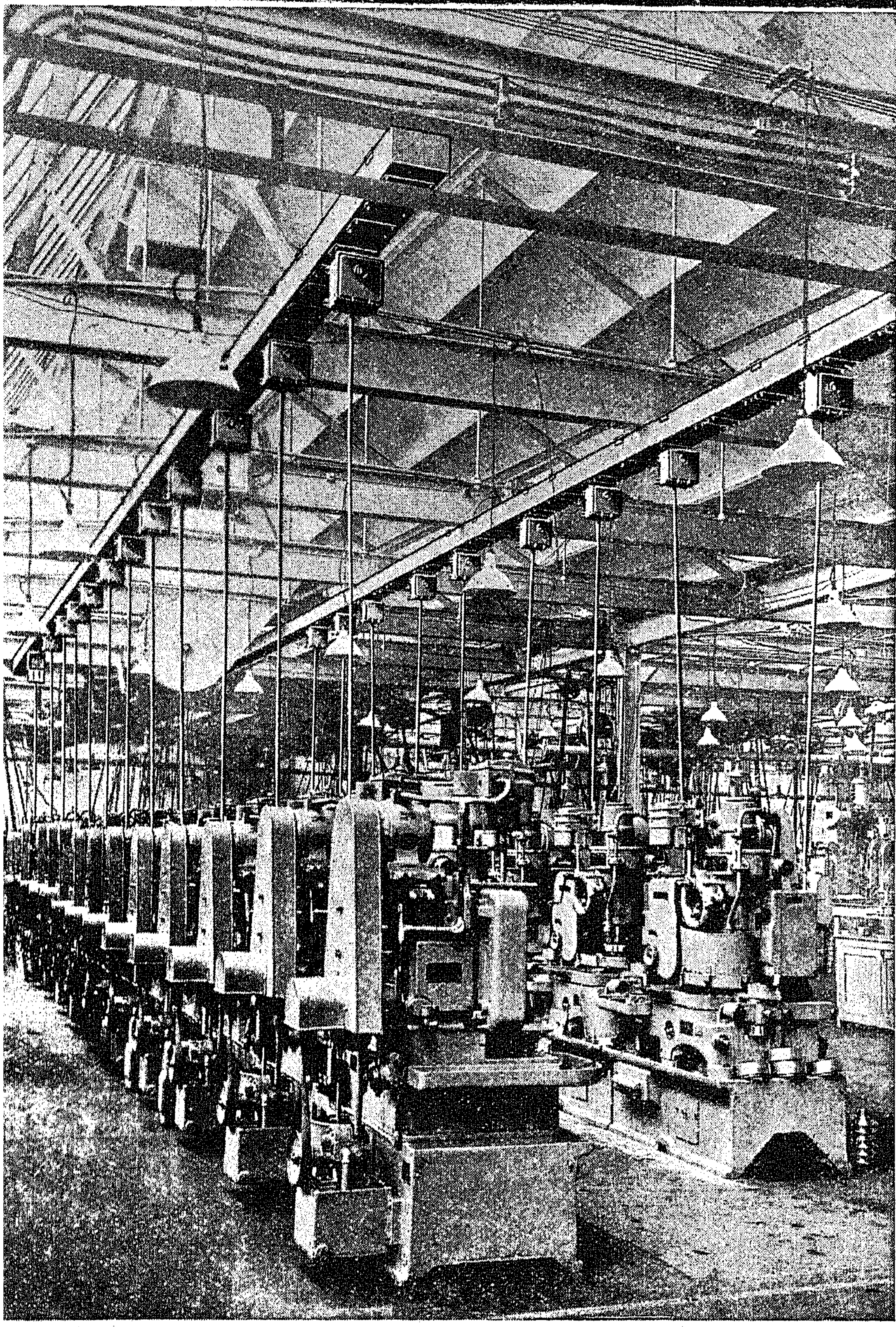

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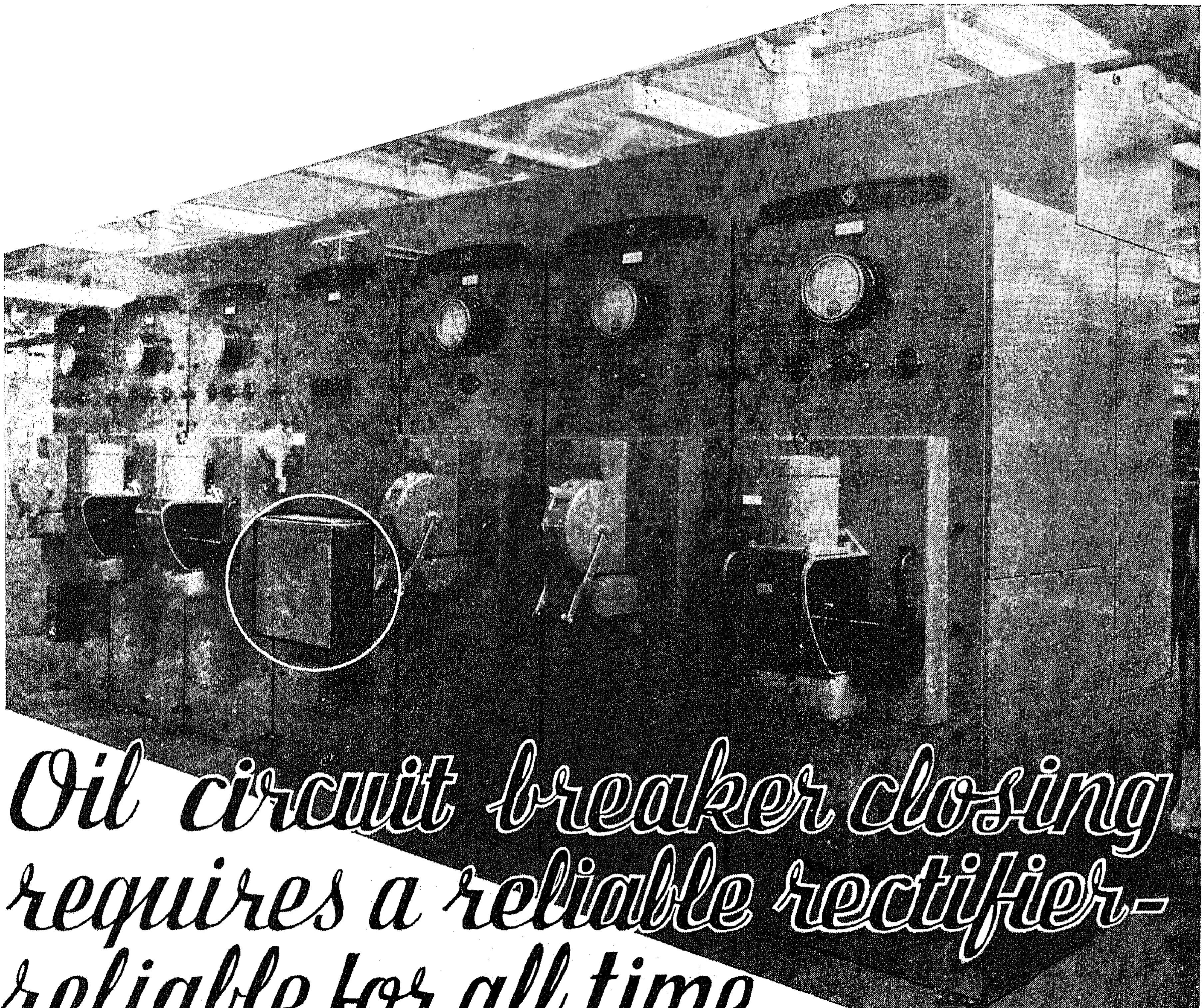

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